

THE LEVELS OF URANIUM AND OTHER ELEMENTS IN LICHENS
AND MOSSES GROWING IN THE ELLIOT LAKE AND AGNEW
LAKE AREAS, ONTARIO, CANADA

by

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via

Dr. D. Balsillie, Liaison Officer, Sudbury Office

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ABSTRACT

The elemental content of various lichens and mosses is reported in relation to distance from the mills, mine exhaust vents and tailings associated with uranium mining and milling at Elliot Lake and Agnew Lake, Ontario. It is clear that elevated levels of uranium (U), iron (Fe) and titanium (Ti) occur in plants growing close to the industrial operations. Elevated levels of lead (Pb) were observed close to the horizontal mine exhaust vent but elsewhere Pb enrichment from the combustion of automobile fuel appeared to mask that derived from vertical exhausts, mills and tailings. Distance related trends were not seen for nickel (Ni), and the higher content in lichens collected around Agnew Lake as compared to Elliot Lake suggests contributions from the Sudbury nickel smelters.

The uranium content of lichens and mosses close to all mining operations was higher than hitherto reported, with levels of around 100 ppm (dry weight) being found near mills and exhausts. However, the levels decreased rapidly to below the 1 ppm detection limit of the X-ray spectrometer used for the routine analysis. Results indicate that Pleurozium and Dicranum among the mosses and Cladonia and Stereocaulon among the lichens are the most useful species for monitoring atmospheric deposition around the Elliot Lake and Agnew Lake areas. The high uranium content found in the aquatic moss Fontinalis from the Serpent River suggests that this plant may be of value in assessing water quality in Northern Ontario streams.

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A. INTRODUCTION

An appreciation of the value of lichens and mosses as indicators of contamination of the environment from industrial activities has increased greatly over the last decade. In all parts of the world, these plants have been used to monitor the levels of more than 25 different elements in studies of environmental quality around smelters, manufacturing plants and urban centres (see reviews by Nieboer et al. 1978; Nieboer and Richardson, 1980; Richardson, et al., 1980; and LeBlanc and Rao, 1974). Both lichens and mosses possess the capacity to accumulate elements via an extracellular ion exchange process and by particulate trapping. These plants do not have roots; therefore in many species the uptake from the substrate is minimal when compared to the uptake from rainwater and dry dust deposition (e.g., Svoboda and Taylor, 1979). Indeed, lichens had accumulated only about 1 ppm dry wt (30 ppm in ash) when collected from uranium rich substrata in Finland (Yliruokanen, 1975).

The Elliot Lake area in Northern Ontario has one of the largest uranium reserves in the world (Robertson, 1968; Frobél, 1977). Dust is generated by many different processing activities associated with the industry: e.g. blasting, crushing, milling and tailings disposal. While lichens and mosses have not been used previously to monitor contamination in the vicinity of uranium mines, it is known that fungi are able to take up this element. Fungi growing on uranium rich black shales accumulated more than 10% of their weight as uranium (Millot et al., 1978). Microalgae have also been shown to accumulate high levels of uranium in laboratory studies (Sakaguchi et al., 1978; Horikoshi et al., 1979; Nakajima et al., 1979). Since lichens are composite plants

consisting of an alga and a fungus growing together in a symbiotic association, it might be expected that they have a considerable capacity for uranium uptake. Lichens have previously been shown to accumulate other metals to a marked degree (Nieboer et al., 1978). Mosses have a similar capacity, but measurements of uranium levels in mosses are scarce. One study indicated that background values in Norway were less than 0.2 ppm for Hylocomium splendens (Steinnes, 1977). Both lichens and mosses have been used to monitor atmospheric fallout of radionuclides derived from nuclear bomb tests and crashing satellites (Gorham, 1959; Svoboda and Taylor, 1979; Taylor et al., 1979; Holm 1977; Holm and Persson, 1978).

The present study was undertaken to provide baseline data on the levels of uranium and other elements in lichens and mosses around the uranium mining centres of Elliot Lake and Agnew Lake. In our original research proposal mention was made of measuring uranium levels in selected surface water samples. Due to the work load involved in obtaining the data presented in this report and because the Ministry of the Environment already has access to data on uranium levels in surface waters around Elliot Lake (see Rasberry and Gorber, 1978), it was decided to concentrate exclusively on the collection and analysis of plant material. Our data indicate that lichens and mosses may be used successfully to monitor uranium contamination and furthermore, provide information on the current background levels of uranium in these plants. After the forthcoming expansion of the industry (Rasberry and Gorber, 1978), the uranium levels could be periodically remeasured and thus indicate whether there was a potential radiation problem associated with dust emissions that might require control (Basuk and Nichols, 1979).

B. MATERIALS AND METHODS

B.1. Collection of Material.

Moss and lichen samples were collected and placed in paper bags. Only the top living portion (about 3-4 cm) of the lichen clumps were collected to reduce the amount of debris and soil contamination. The samples were stored in the paper bags. Samples were collected in the Elliot Lake (Lat. $46^{\circ}23'N$; Long. $82^{\circ}39'W$) and Agnew Lake ($46^{\circ}26'N$; $81^{\circ}37'W$) areas.

B.1.a. Macro-transects. Samples were collected along a 54 km transect from Elliot Lake. The origin of the transect was midway between the Denison Mill and the Quirke Mill and it ran in a southerly direction along Highway 108 and then eastward along Highway 17 (see Fig. 1). Distances were measured on an automobile odometer and the exact position of the collection site was verified by reference to detailed maps and physical features such as streams and contours.

A second macro-transect ran 9.6 km in a southeasterly direction from Agnew Lake (see Fig. 2). The origin of the transect was the Agnew Lake Mill, and the exact position of each site was verified as before. Along this, and the Elliot Lake macro-transect, samples were collected at least 50 m from the road or highway, respectively.

B.1.b. Micro-transects and collections. Figures 3,4,5 and 6 show the location of collection sites in the vicinity of Rio Algom and Denison Mines at Elliot Lake. Brief descriptions of the sampling sites are provided in Appendix I, while species identification, together with the collection codes used for the chemical analyses, are summarized in Appendix II. It is to be noted that more than one code sequence was employed. Distances were measured by metre tape.

B.2. Treatment of Samples

B.2.a. Sample Preparation

The collected lichens and mosses were soaked in distilled water and were then thoroughly washed under running distilled water. Debris and discoloured parts of the sample were removed. The washed samples were allowed to air dry and were subsequently crushed and ground in a mortar with pestle using liquid nitrogen to facilitate the process. The resultant powder was passed through a 70-mesh stainless steel sieve, was oven dried at 80°C for 24 h, and was then stored in sealed vials which were kept in a desiccator until use.

B.2.b. Pellet preparation. Dry plant powder (2 g samples) was shaken with 0.5 g of Hoechst 'C' wax in plastic vials for five minutes on a mechanical shaker. The powder was pressed into a pellet 32 mm in diameter and 2-3 mm in thickness, using a semi-automatic hydraulic press with a pressure of 10 tons for 60 seconds. These pellets were used for the determination of Ni, Fe, Pb and Ti contents of the lichens and mosses and were subsequently archived for future reference.

B.2.c. Ash preparation. As the uranium content in many samples was low, the samples were ashed. This concentration step was carried out as follows: 5 g of oven-dry material were placed in a crucible with a lid and ashed in a muffle furnace. The temperature regime employed was 1 h at 150°C, 2 h at 250°C, 1 h at 350°C and then 20 h at 500°C. The ash was weighed and stored in glass vials in a desiccator. In preparation for the analysis step, 30 mg of ash were weighed out and placed between two sheets of thin mylar clamped in a plastic holder. The loaded plastic holders were stored in desiccators until analysis.

B.3. Analytical Procedures.

B.3.a. X-ray fluorescence spectrometry (XRF). The primary technique used in this study was XRF. The spectrometer was calibrated after every seventh sample with standard lichen material having a known metal content. The standard material was analyzed separately by atomic absorption spectrophotometry, or by XRF using standard addition techniques (see section B.3.b.). Corrected spectrometer counts (see Table I, and Tomassini et al., 1976) for the different samples were compared directly with those in the standard lichen material and the elemental content was calculated from this ratio. All computations were effected by the use of a computer. The XRF-spectrometer output was automatically punched onto computer cards. For Ti, Ni, Fe and Pb, the computer programme employed gave the output in units of ppm ($\mu\text{g/g}$ dry wt of plant material). For U, additional information was punched in manually on the computer cards. This included sample weight, the corresponding ash yield and the amount of ash taken for the uranium analysis. The computer output gave the U content in units of ppm: as $\mu\text{g/g}$ dry wt of plant material, and also as $\mu\text{g/g}$ of plant ash. The latter concentration unit was chosen to allow comparison of the results with those of previous studies (e.g. Yliruokanen, 1975). The actual computer outputs form an appendix to this report. Throughout the written report, all values shown graphically are given in concentration units of ppm ($\mu\text{g/g}$ dry wt).

Details of the X-ray spectrometer and the appropriate instrument settings for each element are summarized in Table II. Further details of the use of XRF analysis for lichen and plant material may be found in Tomassini et al. (1976), Mudroch and Mudroch (1977) and Nieboer et al., (1978).

TABLE I

CALCULATION OF CORRECTED SPECTROMETER COUNTS

Element	Corrected Sample Counts ^{a,b} (sec ⁻¹)	Definition and value of F	Standards
Fe	$C_{2\theta} - (C_{2\theta-2.0})^F$	$C_{2\theta}^*/C_{2\theta-2.0}^*$ $= 1.68 \pm 0.02$	<u>Cladonia rangiferina</u> from Cartier, Ontario
Pb	$C_{2\theta} - \frac{1}{2}(C_{2\theta-0.5} + C_{2\theta+0.5})^F$	$C_{2\theta}^*/\frac{1}{2}(C_{2\theta-0.5}^* + C_{2\theta+0.5}^*)$ $= 1.02 \pm 0.01$	<u>Cladonia rangiferina</u> from Cartier
Ni	$C_{2\theta} - (C_{2\theta-1.0})^F$	$C_{2\theta}^*/C_{2\theta-1.0}^*$ $= 1.23 \pm 0.01$	<u>Cladonia rangiferina</u> from Cartier
Ti	$C_{2\theta} - (C_{2\theta-1.5})^F$	$C_{2\theta}^*/C_{2\theta-1.5}^*$ $= 1.03 \pm 0.03$	<u>Cladonia rangiferina</u> from Cartier
U ^c	$C_{2\theta} - (C'_{2\theta})^F$	$C_{2\theta}^*/C'_{2\theta}^*$ $= 0.99 \pm 0.02$	<u>Cladonia rangiferina</u> from Manitoulin Island, Ont.

a. The angle 2θ (theta) corresponds to the detector setting in degrees (see Table II). Corrected counts in counts/second are denoted by C and are evaluated at the analytical angle of 2θ and at the background angle(s), for example in the case of Pb at $2\theta \pm 0.5$.

b. The correction factor F takes into account tube-target contamination due to the tungsten source and sloping backgrounds. F was evaluated for each experimental run. The superscript * indicates that the counts refer to the blank (metal-free sample).

c. $C'_{2\theta}$ corresponds to: $\frac{0.50}{3.75} (C_{2\theta+3.75} - C_{2\theta-0.5}) + C_{2\theta-0.5}$

TABLE II
SPECTROMETER DETAIL^a

PARAMETER	VALUES IN INDIVIDUAL ANALYSIS				
	U	Pb	Ni	Fe	Ti
X-ray tube:					
Anode type	W (tungsten)	W	W	W	W
Voltage (kV)	95	95	50	40	50
Current (mA)	20	20	40	20	40
Crystal ^b	LiF	LiF	LiF	LiF	LiF
Collimator	fine	fine	fine	fine	fine
Counter ^c	gfp + scint.	gfp + scint.	gfp + scint.	gfp	gfp
Analytical line	$L\alpha_1$	$L\beta_1$	$K\alpha_{1,2}$	$K\alpha_{1,2}$	$K\alpha_{1,2}$
2θ (degrees) ^d	26.25	28.39	48.81	57.68	86.29
Background angles (degrees)	25.75/29.50	27.89/28.89	47.81	55.68	84.79
Counting time (sec)	40/100/40	40/100/40	40/40	20/40	100/40

- a. A Phillips X-ray spectrometer, Model PW 1220, was employed. All samples were rotated on their own axis during the analysis, vacuum was used for U and Ni.
- b. LiF, lithium fluoride (200) analyzing crystal.
- c. gfp, gas flow proportional counter; scint., scintillation counter.
- d. The exact value of angles will change slightly with the alignment of the crystal and was optimized each time the spectrometer was used.

B.3.b. Standardization. The Fe, Ni, Pb contents of subsamples of the standard lichen powder used in the preparation of the primary-standard lichen pellet were determined by atomic absorption spectrophotometry. The powder was wet-oxidized in 1:1 (v/v) HNO_3 /72% HClO_4 and then analysed by AA using a Perkin Elmer 703 instrument using standard procedures (Perkin Elmer, 1978). The 1000 ppm stock solutions which were diluted for AA analysis were made up and standardized as described by Tomassini et al. (1976). The Ti content of the standard pellet was determined by reference to a standard curve resulting from an addition technique described by Tomassini (1976).

For uranium, a standard addition method was also employed. Stock solutions containing 1000 ppm uranium were prepared by dissolving either uranium acetate (Baker, analysed reagent grade) or uranium nitrate in one of dilute acid ($2 \times 10^{-2} \text{M HNO}_3$) or distilled water. The stock solution was diluted appropriately, and then suitable aliquots were added to 5-g dry weight samples of Cladonia rangiferina powder prepared from samples collected on Manitoulin Island. This collection site was c. 100 km, S.E. of Elliot Lake and contained no detectable uranium. The amount of uranium solution added was sufficient to yield powders with, for example, 2,4,6,8 and 16 ppm of uranium. The enriched lichen samples were then ashed as described above and 30 mg of ash were placed between mylar films and analysed by XRF. The resultant calibration curve (Fig. 7) shows corrected counts plotted against the amount of uranium on the mylar in μg . As with the other metals, a single standard (in this case, of course, ash sample on mylar) was employed. The spectrometer was recalibrated with this standard after every seven samples.

C. RESULTS

C.1. Preamble. The elemental contents of all the lichens and mosses sampled are given in the computer print-out which forms an appendix to this report. Some results are also presented in graphical form to display relationships between the elemental content and distance from the various mining operations. All metal concentrations in plant material plotted in the figures are expressed as ppm ($\mu\text{g/g}$ oven dry-wt). The figures may be found at the end of section C, on pages 27-50.

C.2. The Elemental Content of Different Lichens and Mosses. In the present study, several different lichens and mosses were collected to determine which might be most useful as monitors of atmospheric deposition. Several different species of each plant were collected at each collection site on transects from exhausts, tailings, etc. It is evident from the chemical analysis results that different species absorb different amounts of particular elements. However, if the elemental contents of two species in relation to distance from an exhaust emission are plotted separately, they show the same trend, even though the absolute values vary considerably between species. Thus, the lead content in ppm ($\mu\text{g/g}$ dry wt $\pm$ standard deviation) of a number of different species collected from similar sites was as follows: Dicranum 77 ± 28 ; Pleurozium 52 ± 12 ; Umbilicaria 49 ± 5 ; Stereocaulon 32 ± 6 ; Sphagnum 32 ± 6 ; Cladonia 26 ± 6 ; Polytrichum 22 ± 6 . Consequently, on a transect the same species should be collected from each sampling site. The results are then easier to interpret because distance from a contamination source is the main variable.

The lichens and mosses which gave consistent results and also occurred at most collection sites were Pleurozium, Dicranum and Cladonia.

The elemental content of Sphagnum seemed to vary rather widely especially if the collection site was unusually wet (see Pakarinen, 1977). A number of species which accumulated high levels of elements did not occur widely enough to be useful indicators of overall trends (i.e., Leucobryum and Fontinalis among the mosses and Umbilicaria among the lichens (see also Groet, 1976)).

C.3. The Elemental Content of Plants on the Macro-transects.

The levels of Fe, Pb and U were found to be elevated above a distance-independent background value within 2 km of the Agnew Lake Mill and within 5 km of the origin of the Elliot Lake transect. This is illustrated by the data for the lichen Cladonia in Figures 8,9,10 and 11.

C.4. The Elemental Content of Plants on the Transects from Mine Exhausts.

Lichens collected near the horizontal exhaust known as Quirke No 1 East showed elevated levels of Fe, Ti, Pb and U (Figs. 12,13,14). In addition, the Fe:Ti elemental ratio of plants close to the exhaust was higher showing that Fe-rich particulates were being discharged (Figs. 15,16). A similar trend was found for mosses though the values of the ratio were higher.

It is of interest to note that the value of the Fe/Ti ratio levels off to about 8 for Cladonia spp. and to approximately 10 for mosses (Figs. 15,16). The Fe/Ti ratio is rather constant for samples collected in rural areas of Canada without significant atmospheric deposition of either element. Thus values for Cladonia spp. have been determined to be 8 ± 1 (New Brunswick), 9 (Northern Ontario) and 10 ± 2 (Canadian Arctic) (see Nieboer et al., 1978). This lack of variability reflects the constancy of the Fe/Ti ratio in most rock types due to the tendency of the oxides of these two metals to crystallise together. The trapping

of minute rock particulates by lichens or mosses results in the accumulation of both metals and an Fe/Ti ratio which is similar to that in the parent rock. Unusual Fe/Ti ratios are found around industrial sources which emit one or other of these elements. Consequently, the higher Fe/Ti ratios observed close to exhaust shafts indicate the emission of Fe rich particles. The difference between the Fe/Ti ratios observed in mosses and those found in lichens at the same site likely results from a different degree of leaching and uptake of labile (ionic) Fe. The conclusion that lichens and mosses accumulate particulates efficiently is supported by the observation that the ash content of washed mosses and lichens increased considerably close to emission sources (e.g. Fig. 17).

Similar trends in metal concentrations (e.g. Fig. 18) were observed along the transect from the vertical exhaust on Knowles Island.

C.5. The Elemental Content of Plants near Tailings.

The levels of uranium in lichens near active tailings were enhanced to varying degrees depending on the tailings and position of the plants. The levels did not fall off as rapidly as was the case near the exhaust fans (Fig. 19).

C.6. The Uranium Content of Plants as Measured by Two Different Analytical Methods.

XRF was selected for the routine analysis of uranium in plant ash in this study. However, as an independent check, ten samples were sent to the University of Toronto for analysis by neutron activation using the Slowpoke Reactor. A comparison of the results obtained using the two techniques is given in Table III. It is evident from the data that excellent agreement was obtained between the two independent methods.

Table III. Comparison of Uranium Values Obtained by XRF and Neutron Activation

Sample Code	XRF*		Neutron Activation**	
	ppm of ash	ppm of sample	ppm of ash	ppm of sample
AMG1	2	≈0	4±1	≈ 0
AOE1	5,372	153	6200±300	177±9
DBE1	254	14	230±10	12±1
DCL3	82	3	75±3	3±1
DDB2	714	10	760±20	10±1
DDD2	214	8	180±10	6±1
DDD3	379	14	420±20	15±1
DEB2	810	86	830±30	88±3
EEG1	3,374	67	3100±150	61±3
36R1	58	3	70±3	4±1

* Values obtained by X-ray fluorescence spectrometry at Laurentian University.

** Values obtained by neutron activation using the Slowpoke reactor at the University of Toronto.

Fig. 1. Area map indicating collection sites
for the Elliot Lake macro-transect.

MACRO-TRANSECT

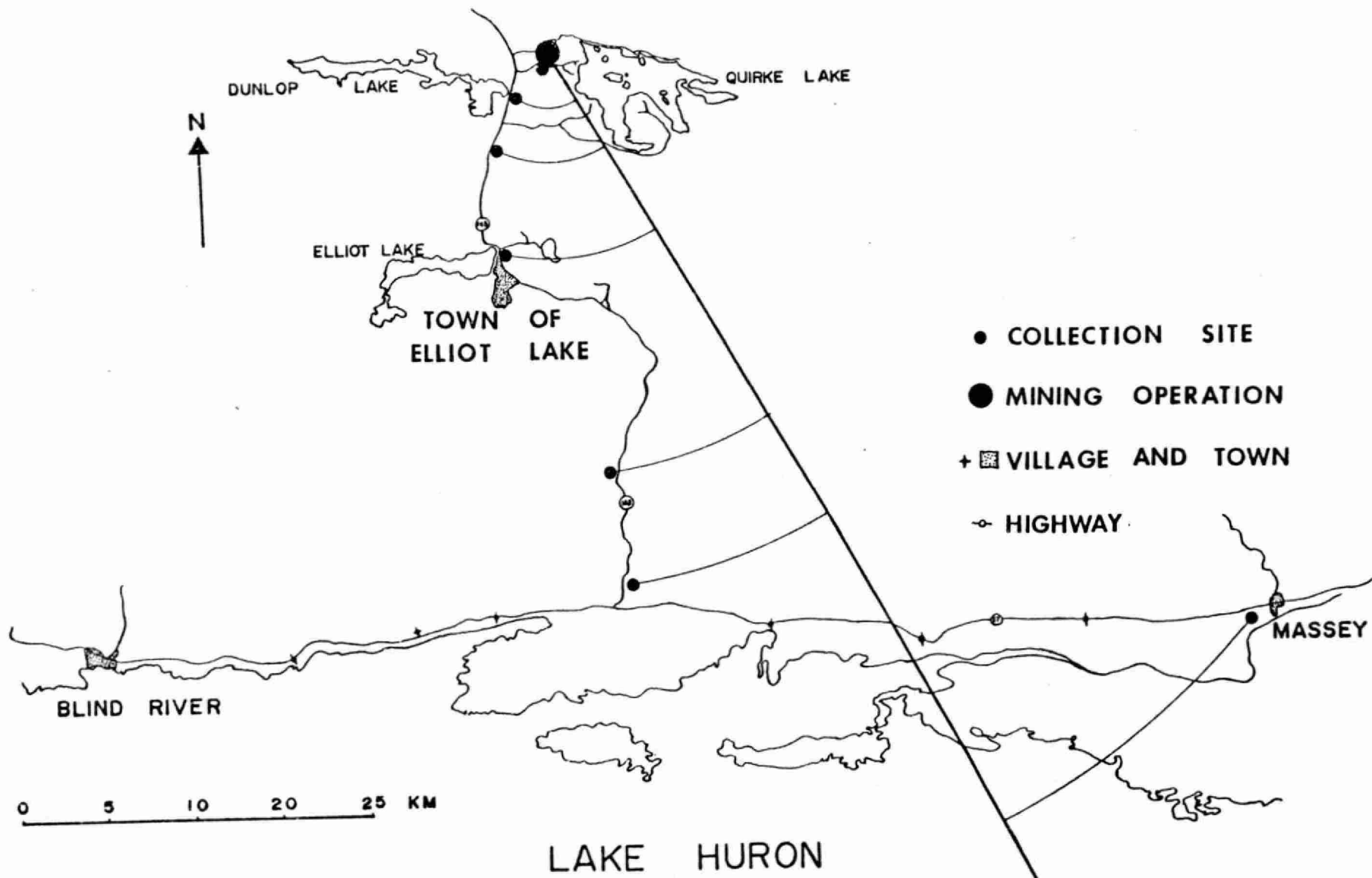


Fig. 2. Area map indicating collection sites for the Agnew Lake macro-transect. The position of Agnew Lake Mining & Milling Operations relative to Hwy 17 is shown in the insert. A brief description of the area enclosed in the large open square, collection site 16, is provided in Appendix I. The remaining symbols have the following meaning:

 , city or town;  , building;
 , road or highway;  , dam;  ,
 water; ---, tailing;  , collection
 area of micro-transect; ●, macro-
 transect samples.

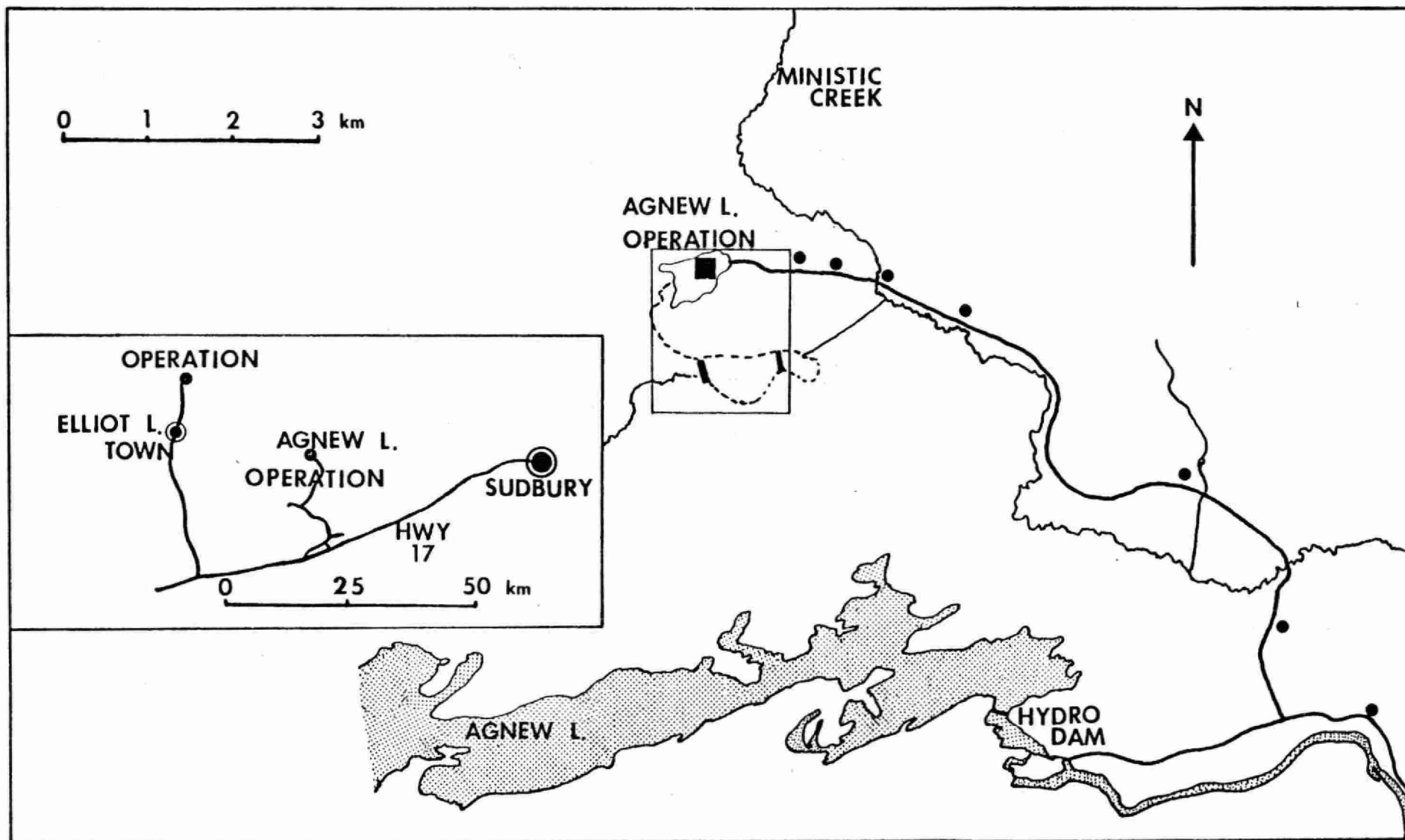


Fig. 3. Area map showing micro-transect collection sites in the vicinity of the Rio Algom and Denison Mining and Milling operations. Brief descriptions of the individual sites 1 to 11 inclusive are provided in Appendix I. The symbols are defined as follows:

—, Road or highway; , Water; ----, Tailing; ■, Horizontal mining exhaust vent; □, Vertical mining exhaust vent;, Micro-tansect collection site; , Building.

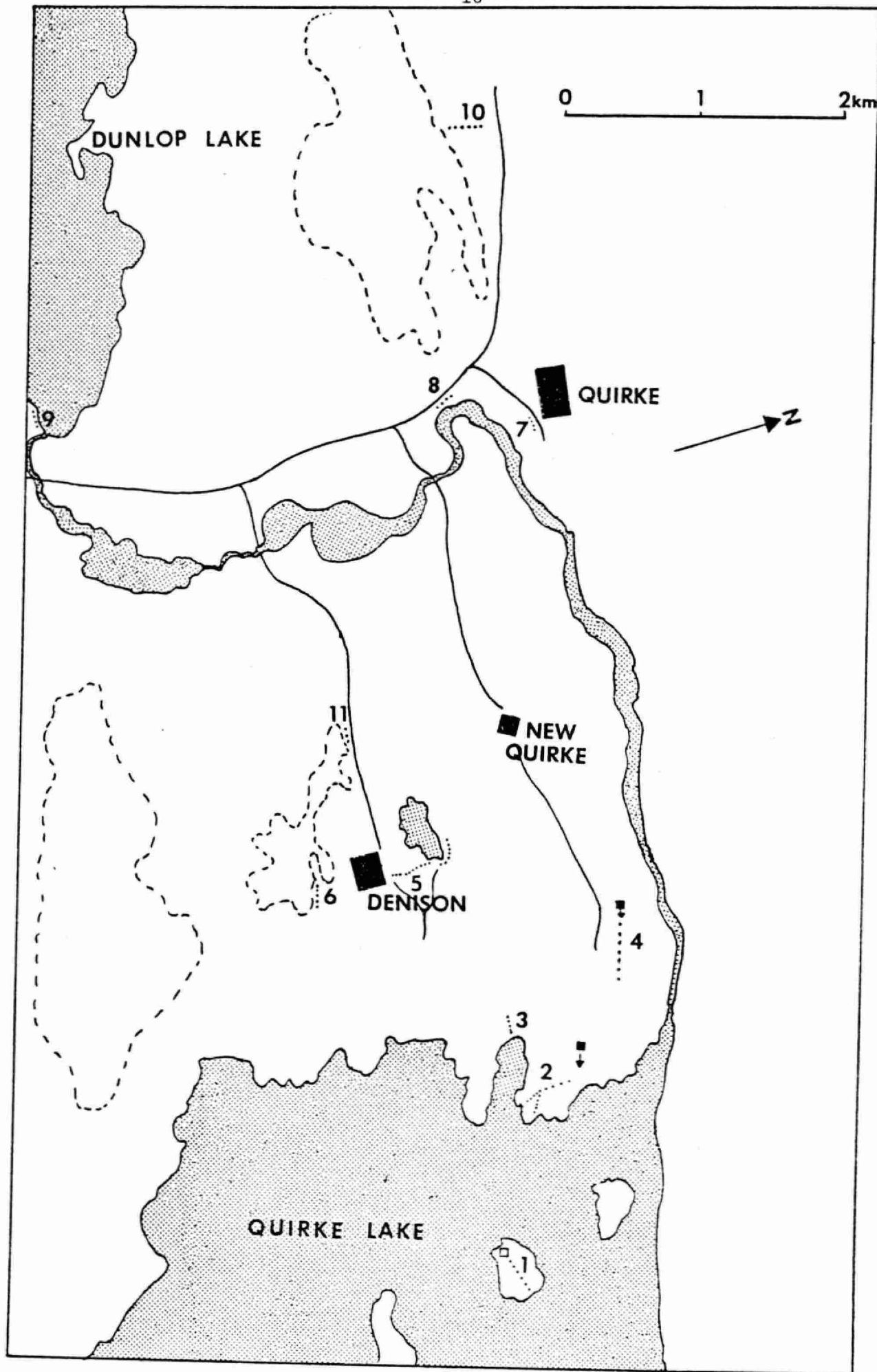


Fig. 4. Area map showing micro-transect collection sites in the vicinity of the town of Elliot Lake. Brief descriptions of the individual sites 12 to 15 inclusive are provided in Appendix I. The symbols are defined as follows:

—, Road or highway; , Town; ,
Water; , Marsh; ---, Tailing; ,
Micro-transect collection site; ,
Building.

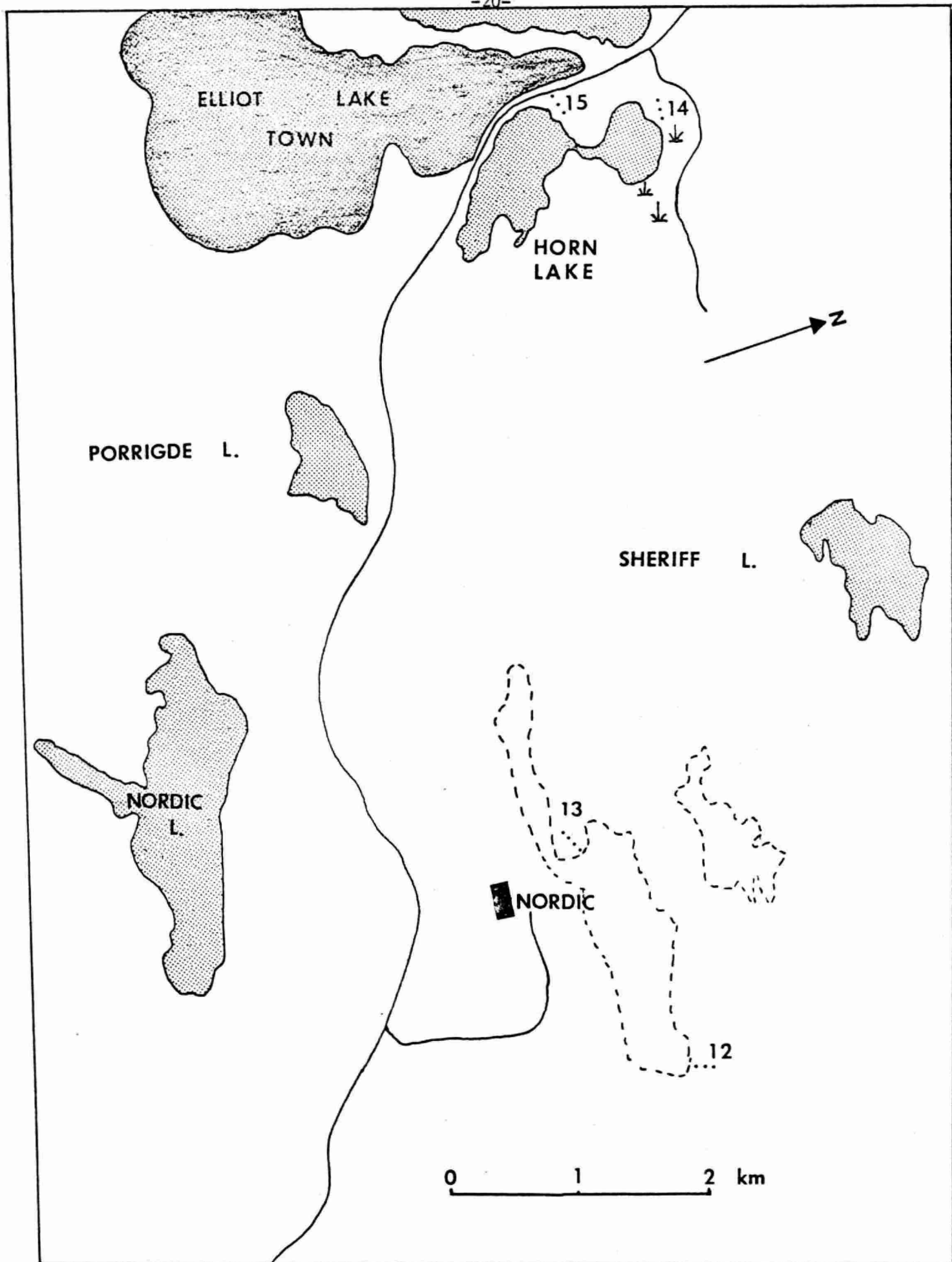


Fig. 5. Detailed sketch of site 4, corresponding to the due-East micro-transect from the Rio Algom Quirke-1E Mining Exhaust Vent.

A brief description of this site may be found in Appendix I.

0 50 100 m

EXHAUST 1 EAST COLLECTION TRANSECT

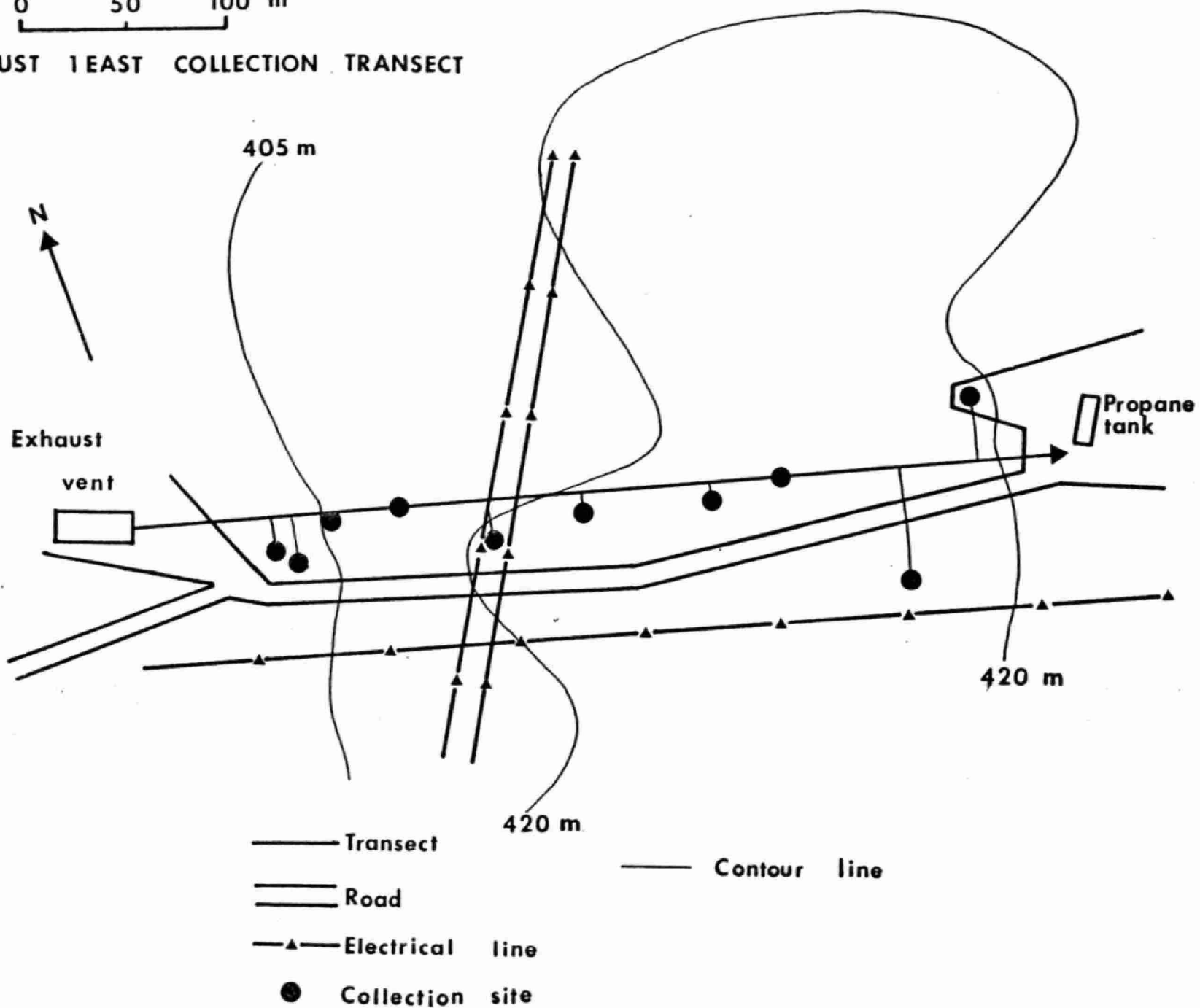


Fig. 6. Detailed sketch of site 10, corresponding to the NE micro-transect from the margin of the Rio Algom Quirke active tailings.

A brief description of this site may be found in Appendix I.

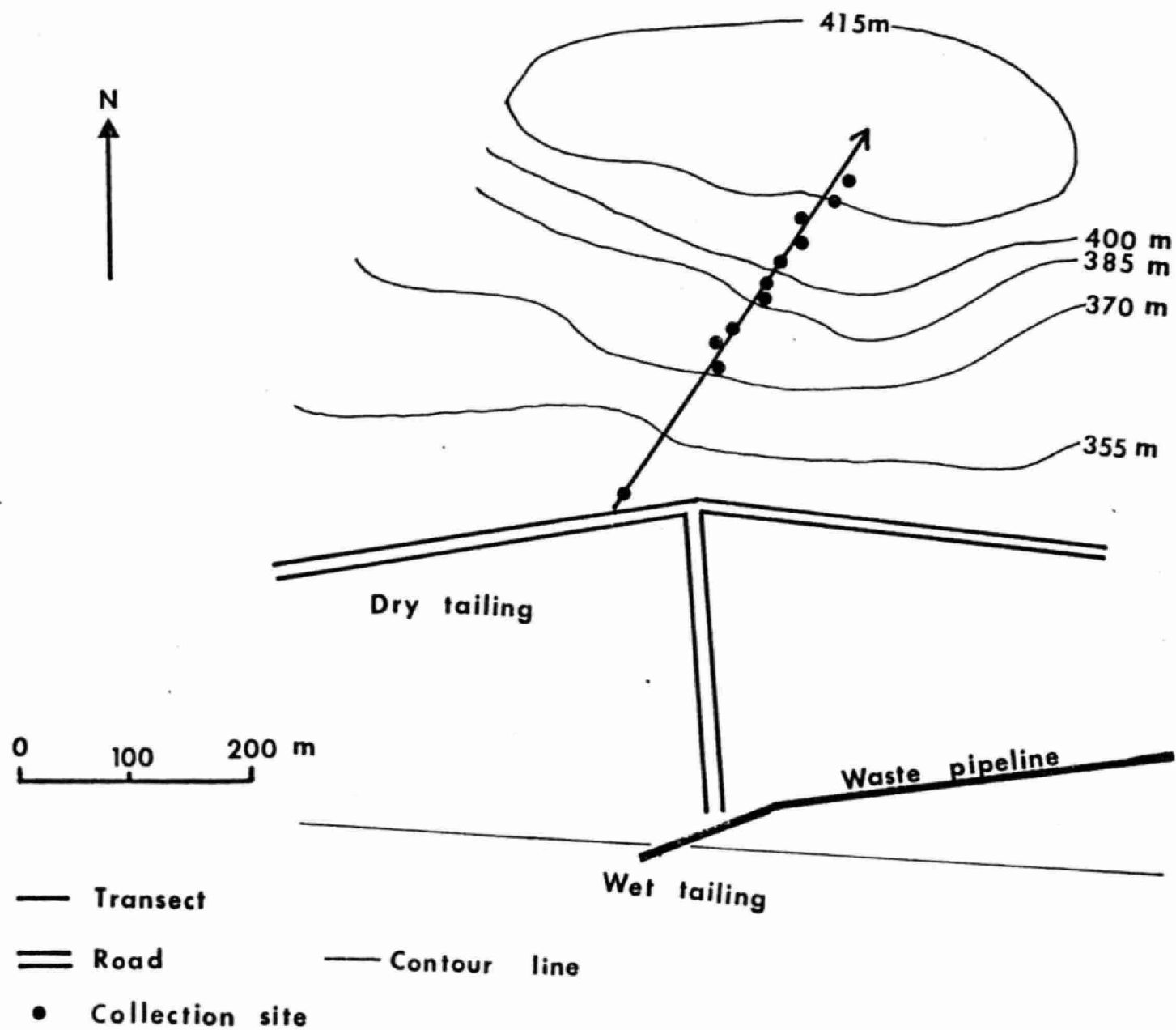


Fig. 7. Spectrometer calibration curve for uranium. A plot of the net XRF spectrometer intensity (corrected counts) as a function of the amount of uranium in a specified amount of lichen ash.

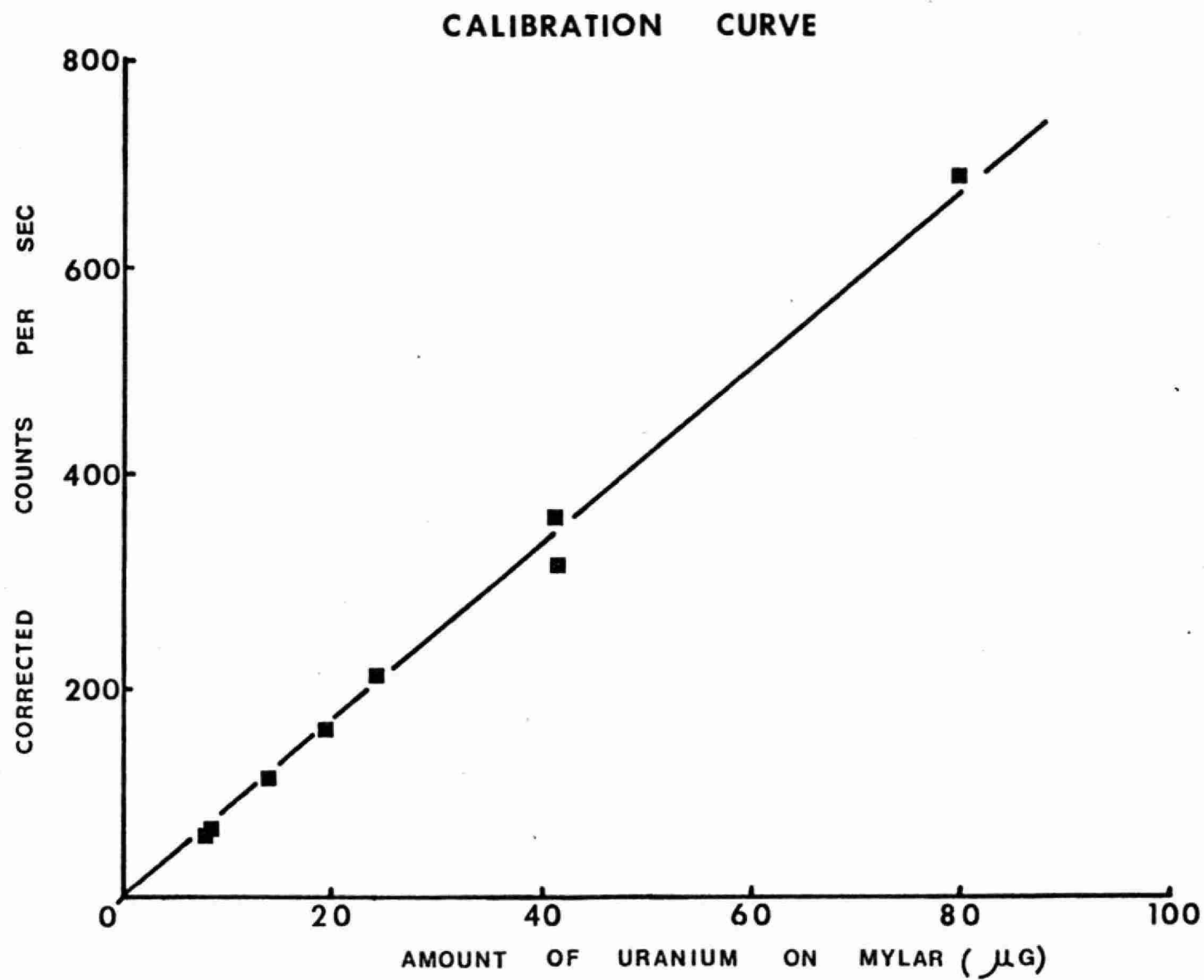


Fig. 8. Lichen uranium content as a function of distance along the Elliot Lake macro-transect.

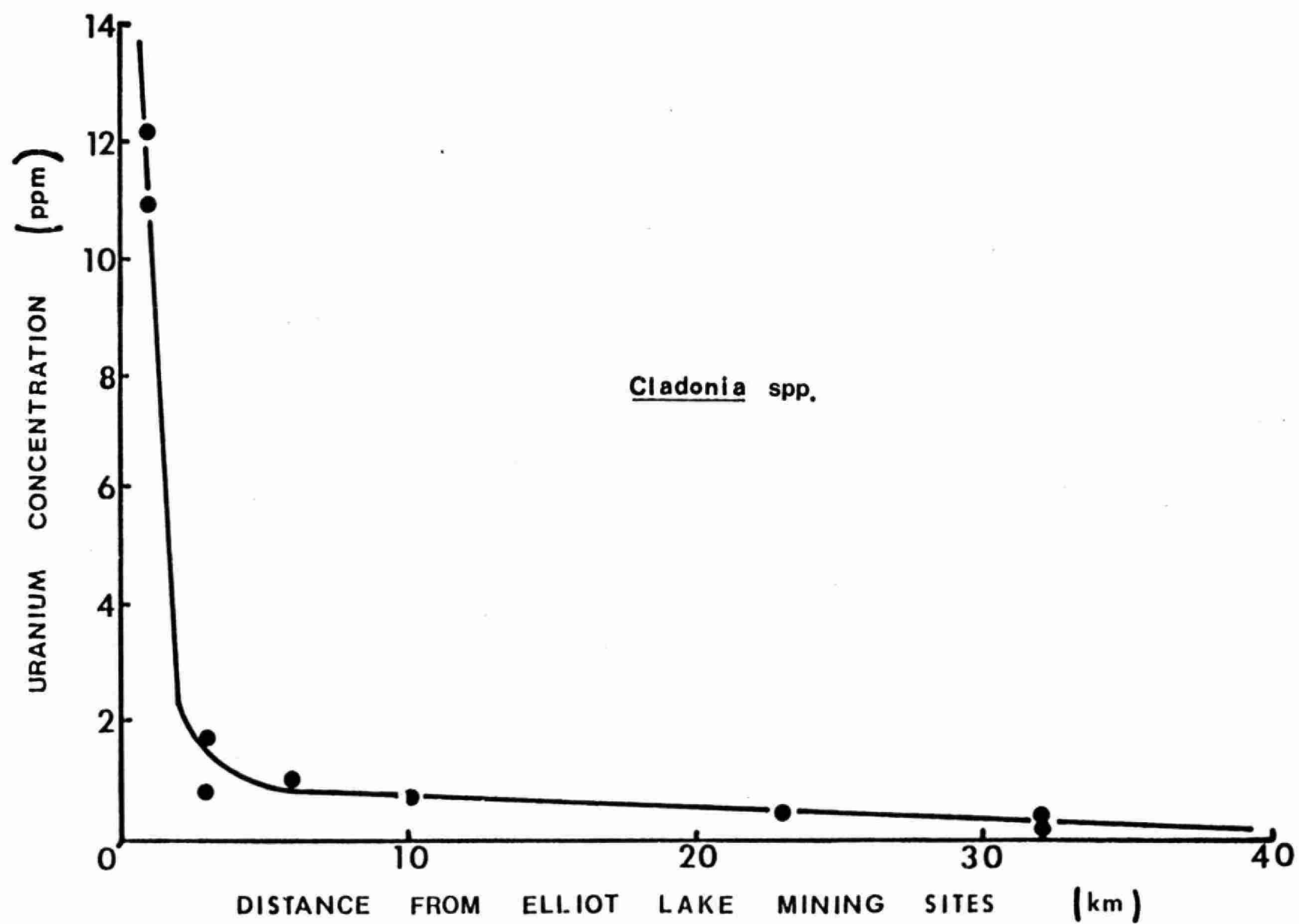


Fig. 9. Lichen uranium content as a function of
distance along the Agnew Lake macro-
transect.

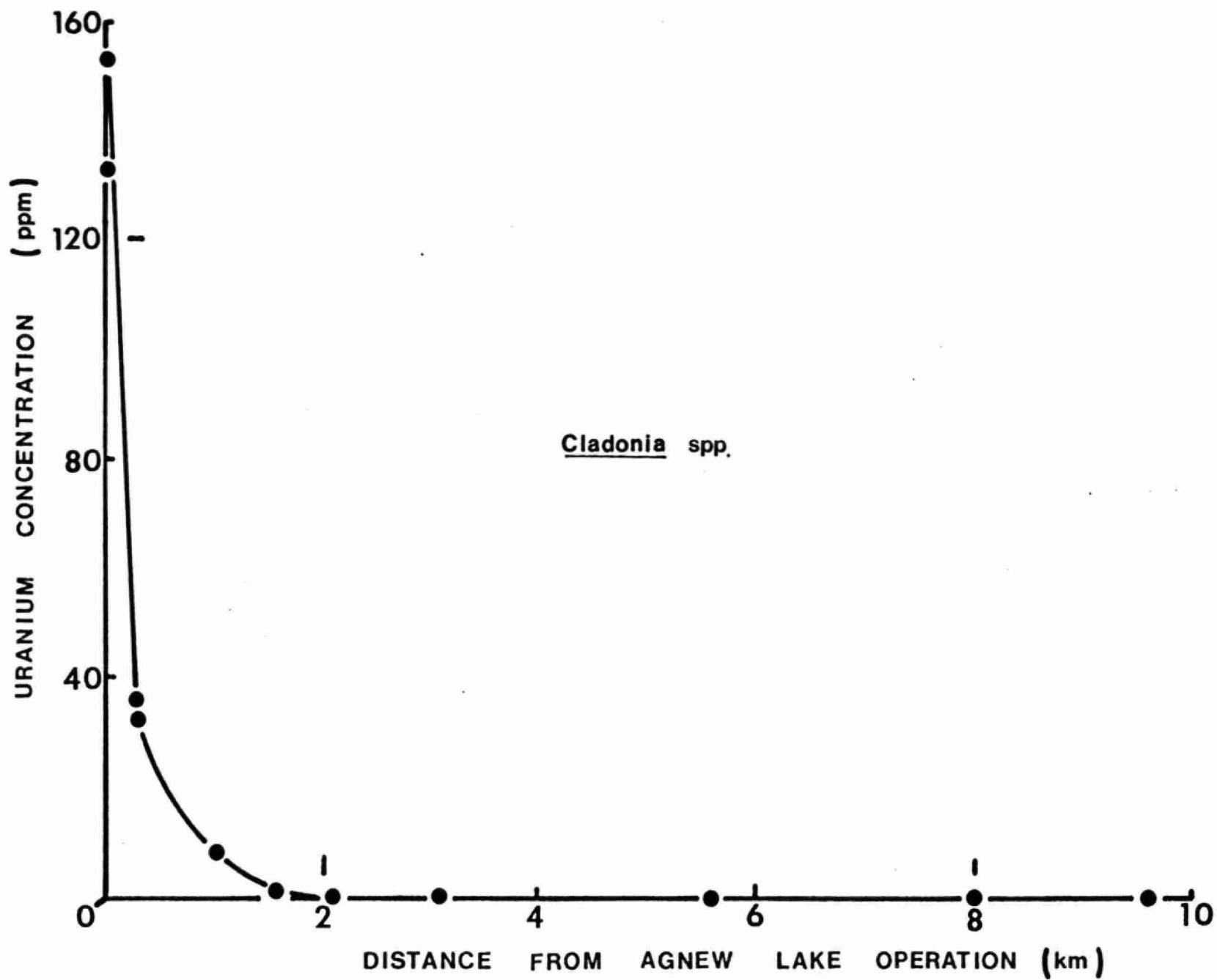


Fig. 10. Lichen iron content as a function of distance along the Agnew Lake macro-transect. Cl. denotes Cladonia.

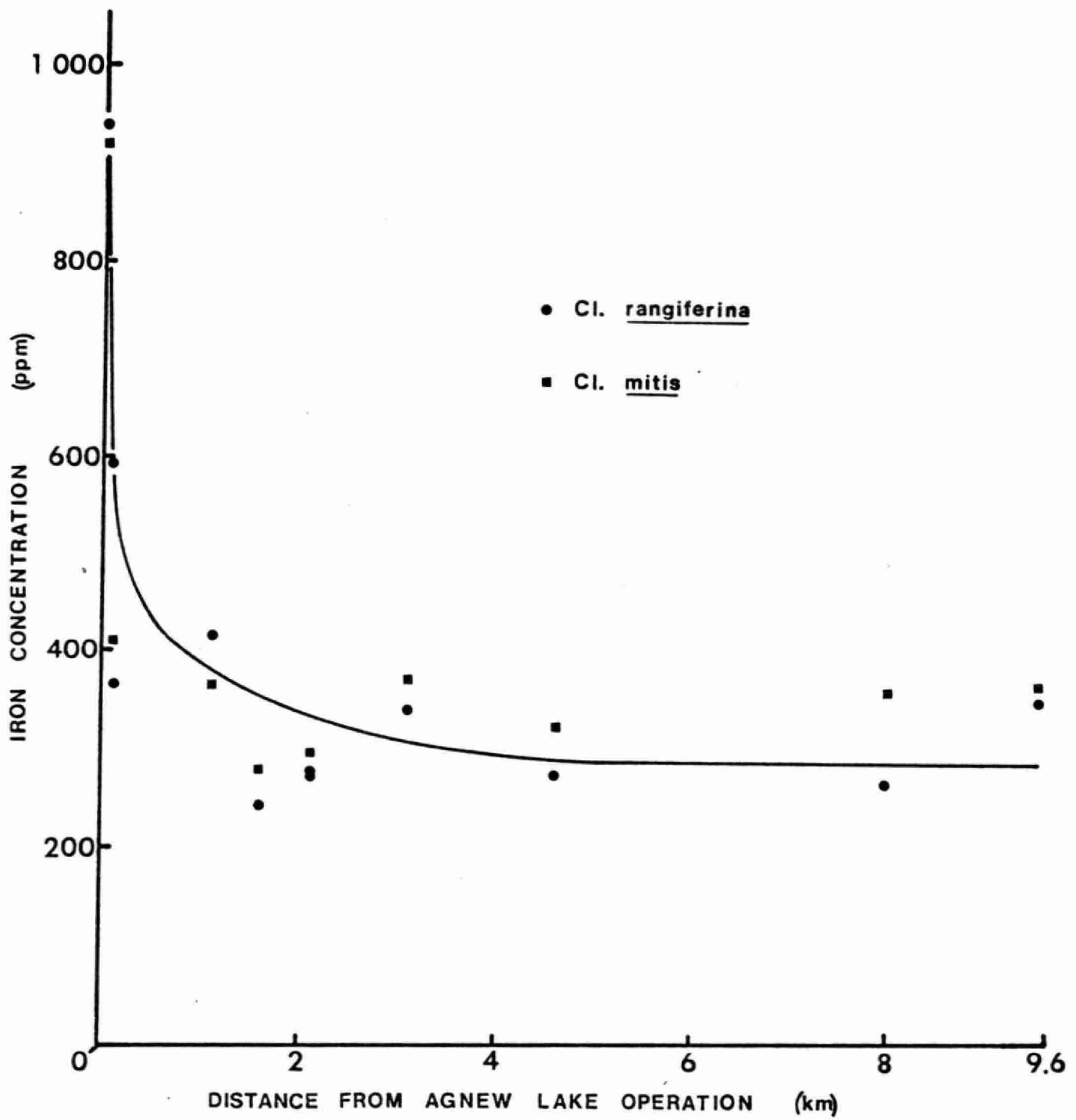


Fig. 11. Lichen lead content as a function of distance along the Agnew Lake macro-transect. Cl. denotes Cladonia.

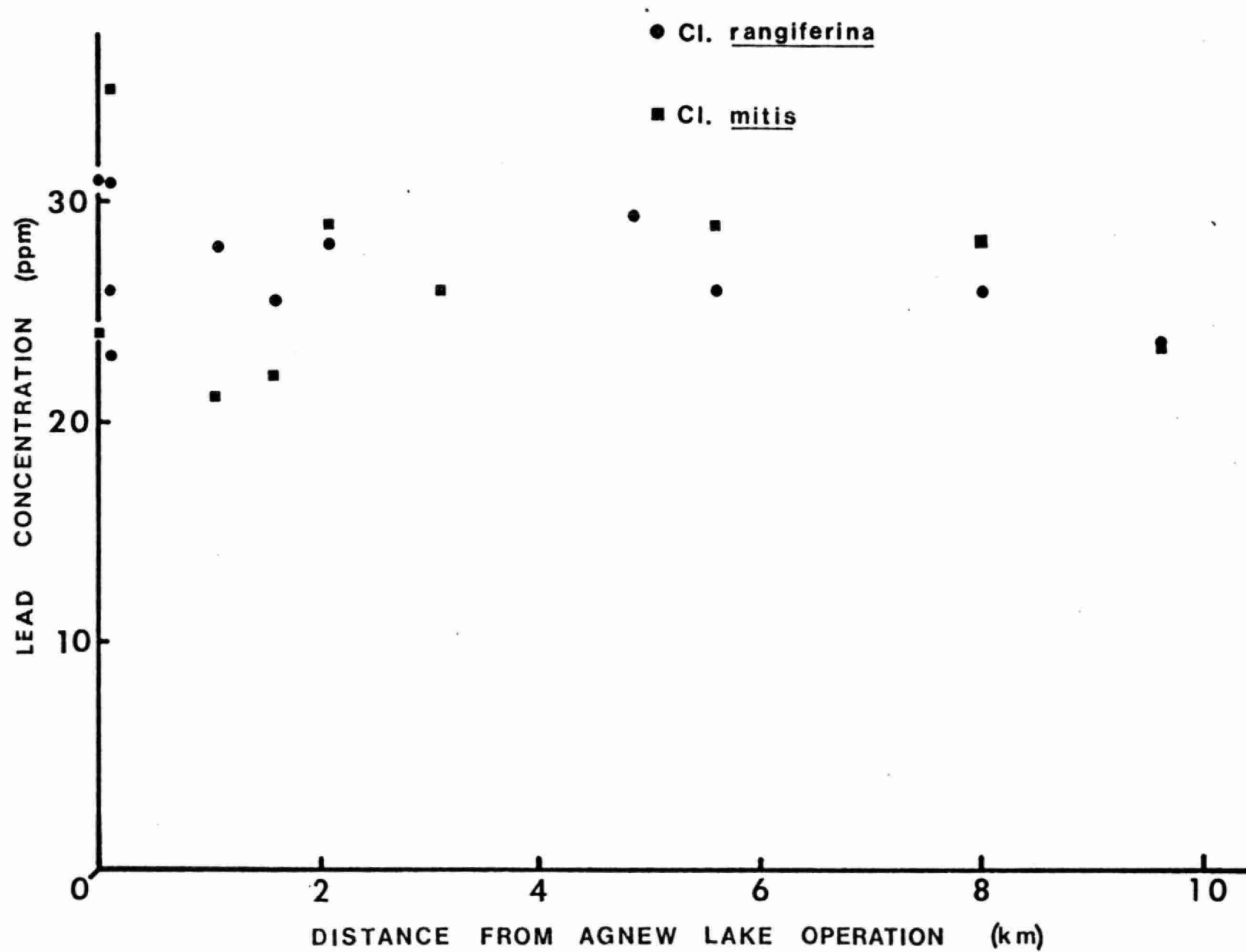


Fig. 12. The uranium in lichen and moss samples collected along the micro-transect from the Rio Algom Quirke-1E Mining Exhaust Vent. See Fig. 5 for the detailed sketch of this transect.

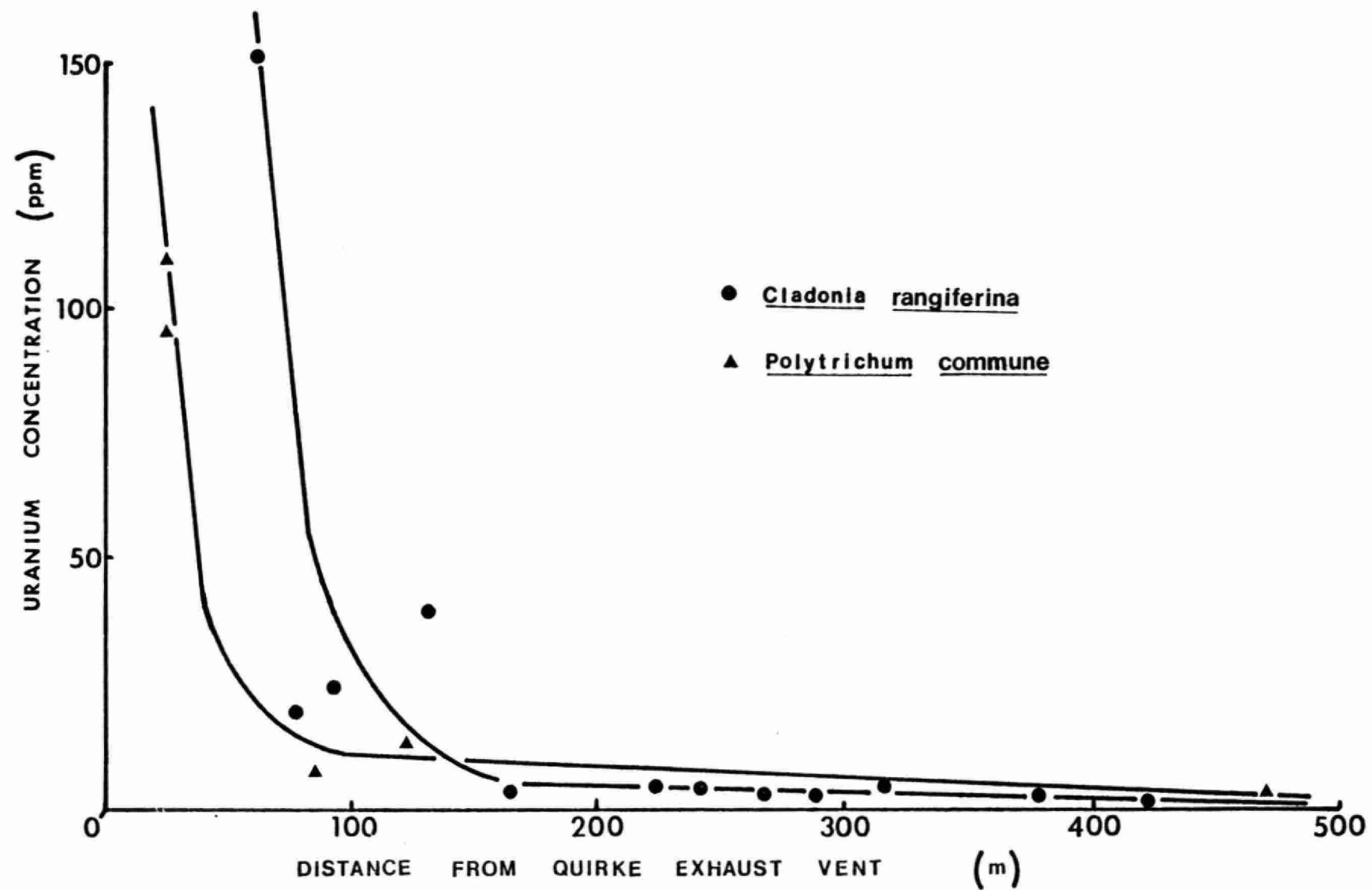


Fig. 13. The iron and lead contents of the lichen Cladonia rangiferina as a function of distance measured along the micro-transect from the Rio Algom Quirke-1E Mining Exhaust Vent. Cl.denotes Cladonia.

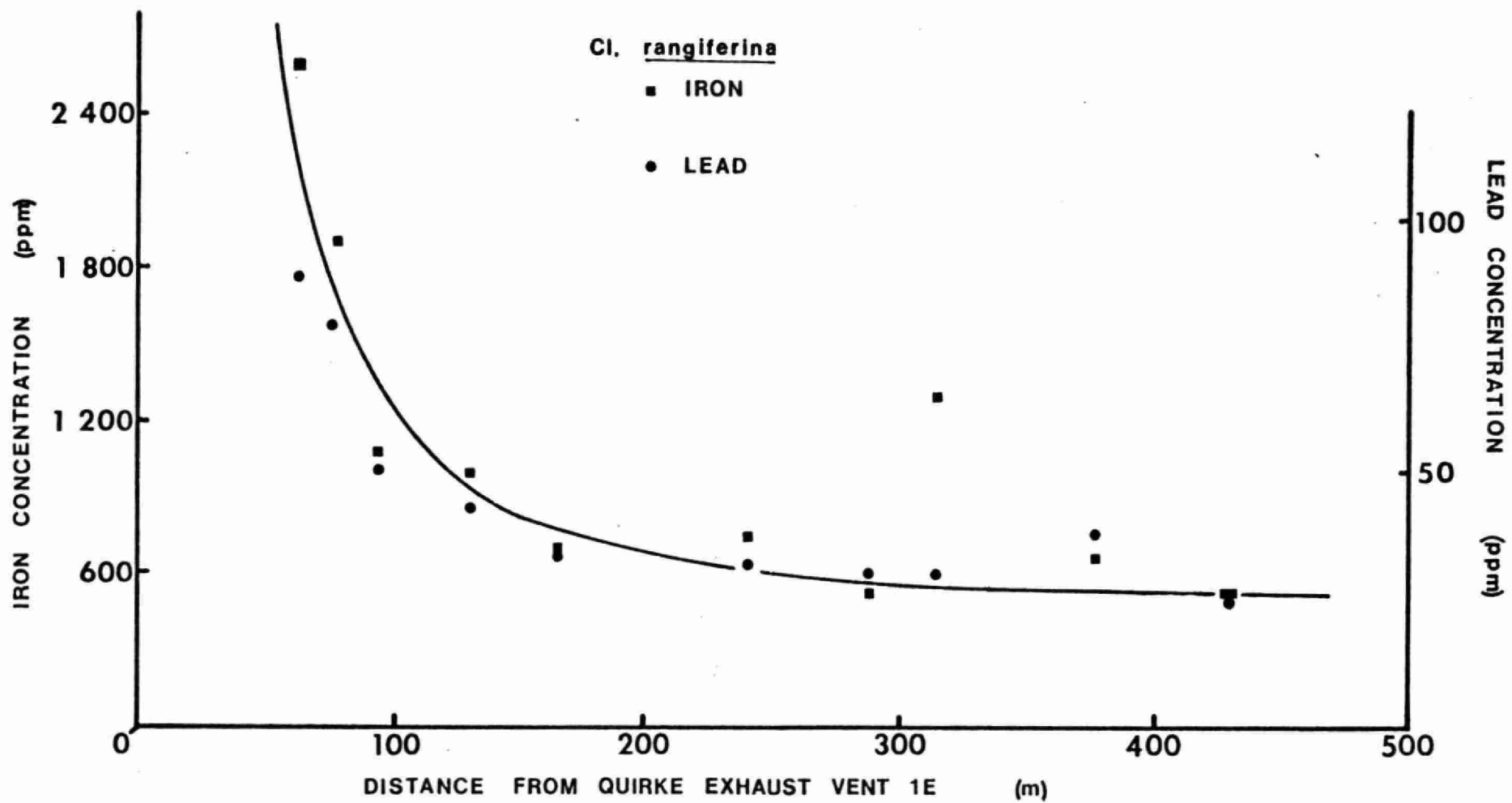


Fig. 14. The iron content of selected mosses as a function of distance measured along the micro-transect from the Rio Algom Quirke-1E Mining Exhaust Vent.

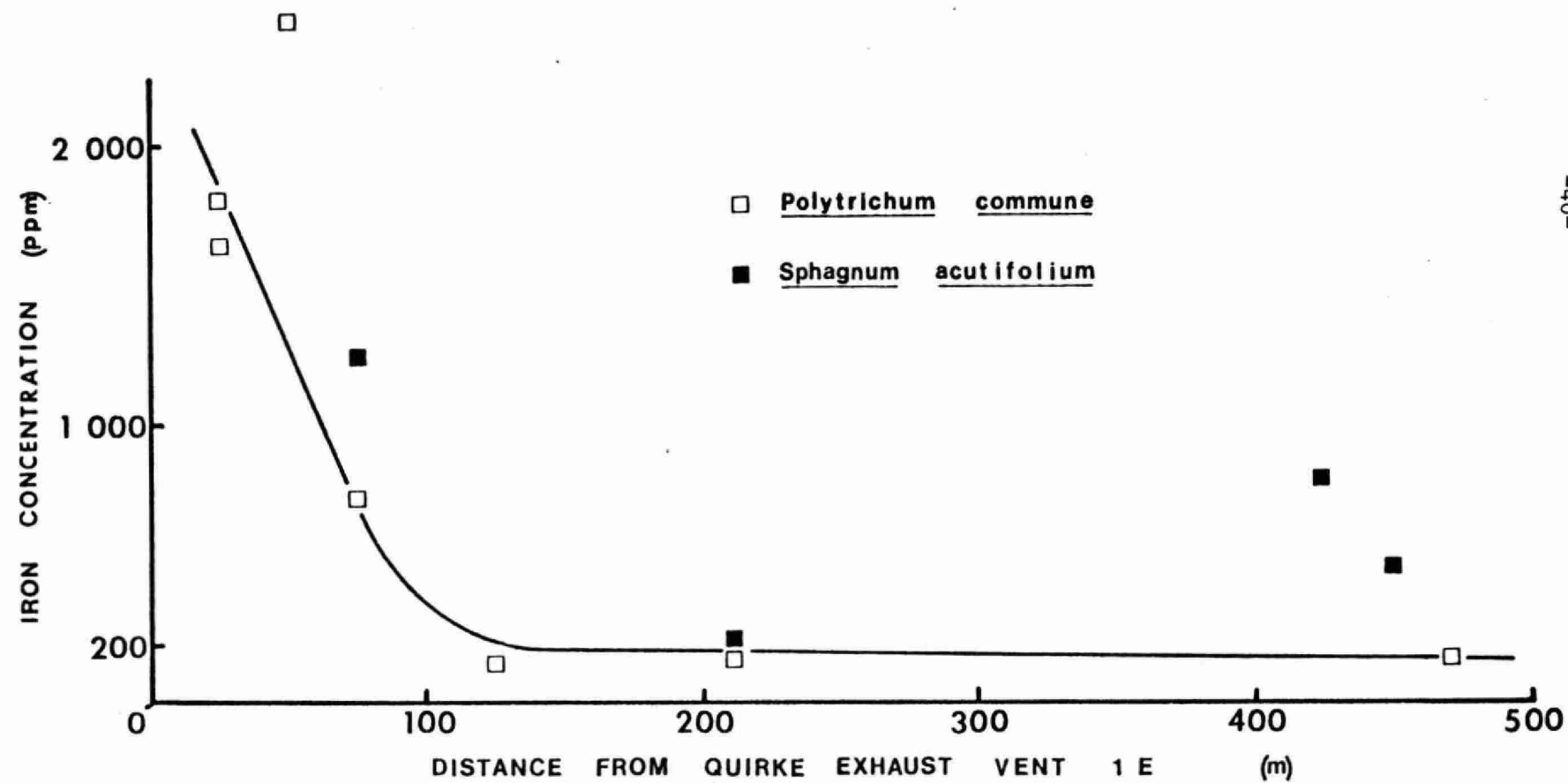


Fig. 15. Iron-titanium elemental ratios for lichen samples
as a function of distance measured along
the micro-transect from the Rio Algom
Quirke-1E Mining Exhaust Vent.

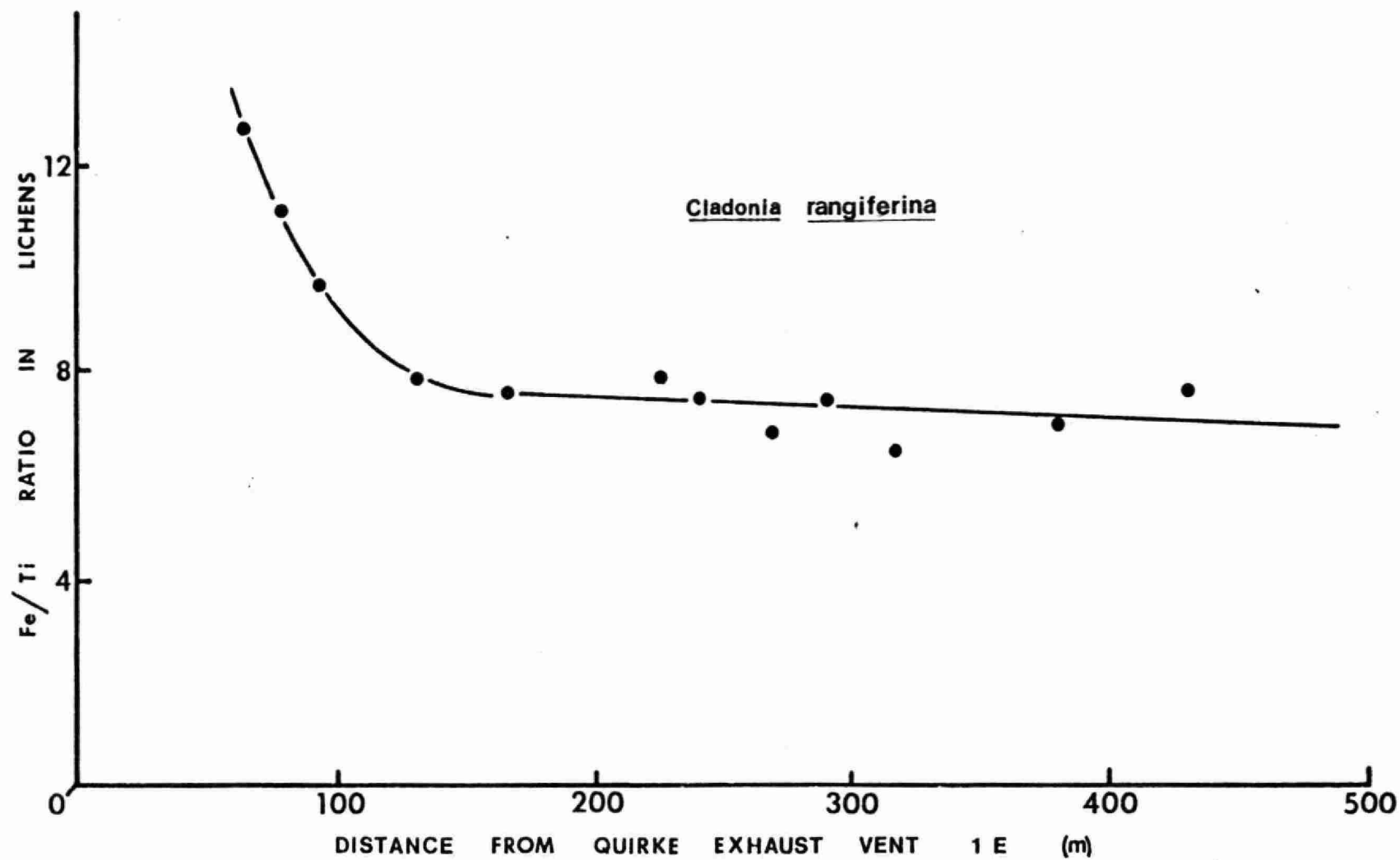


Fig. 16. Iron-titanium ratios for mosses as a function of distance measured along the micro-transect from the Rio Algom Quirke-1E Mining Exhaust Vent.

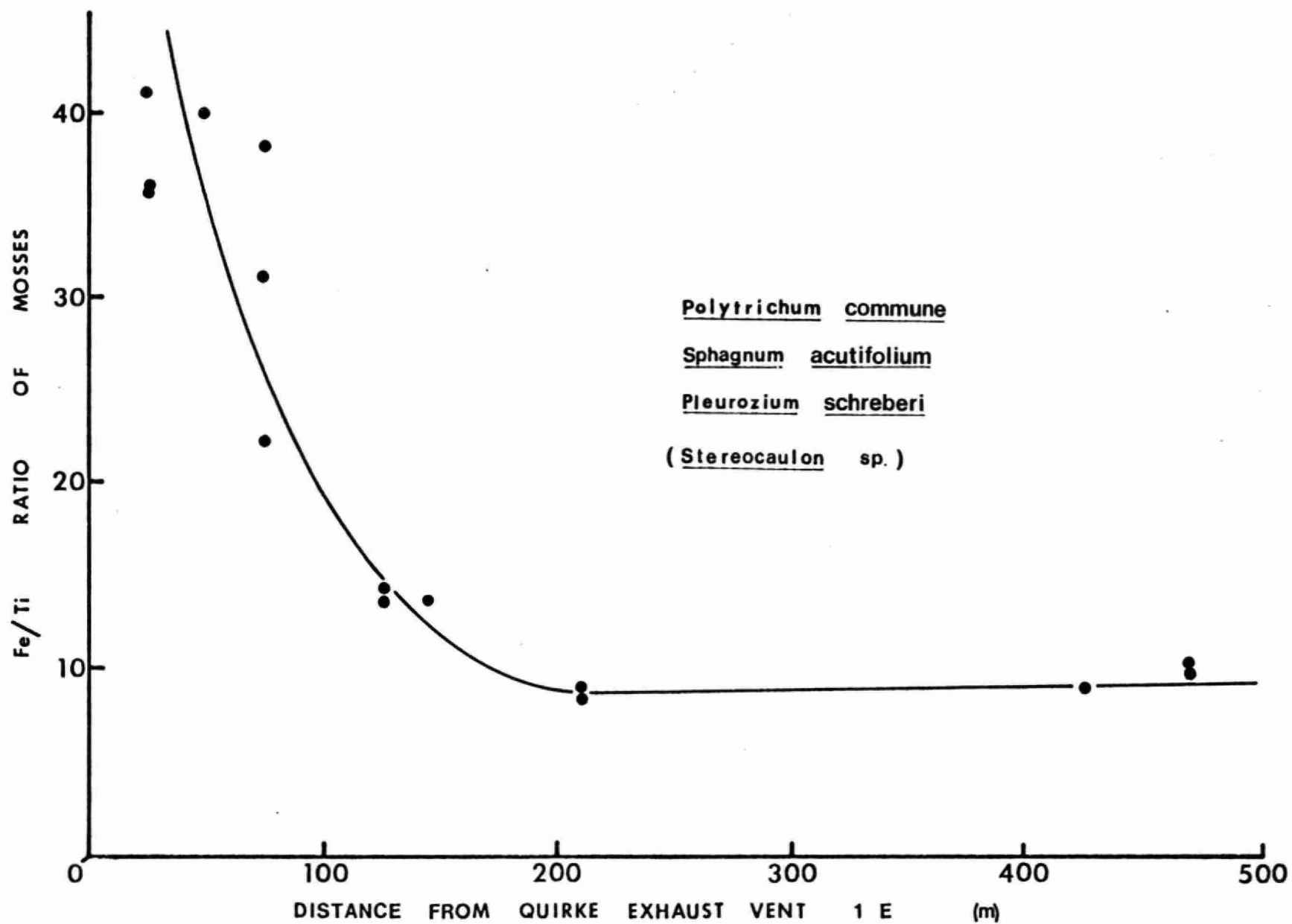


Fig. 17. Amount of ash obtained for 5g (dry wt)
of lichen material plotted as a function
of distance of the collection site from
the Rio Algom Quirke-1E Mining Exhaust
Vent.

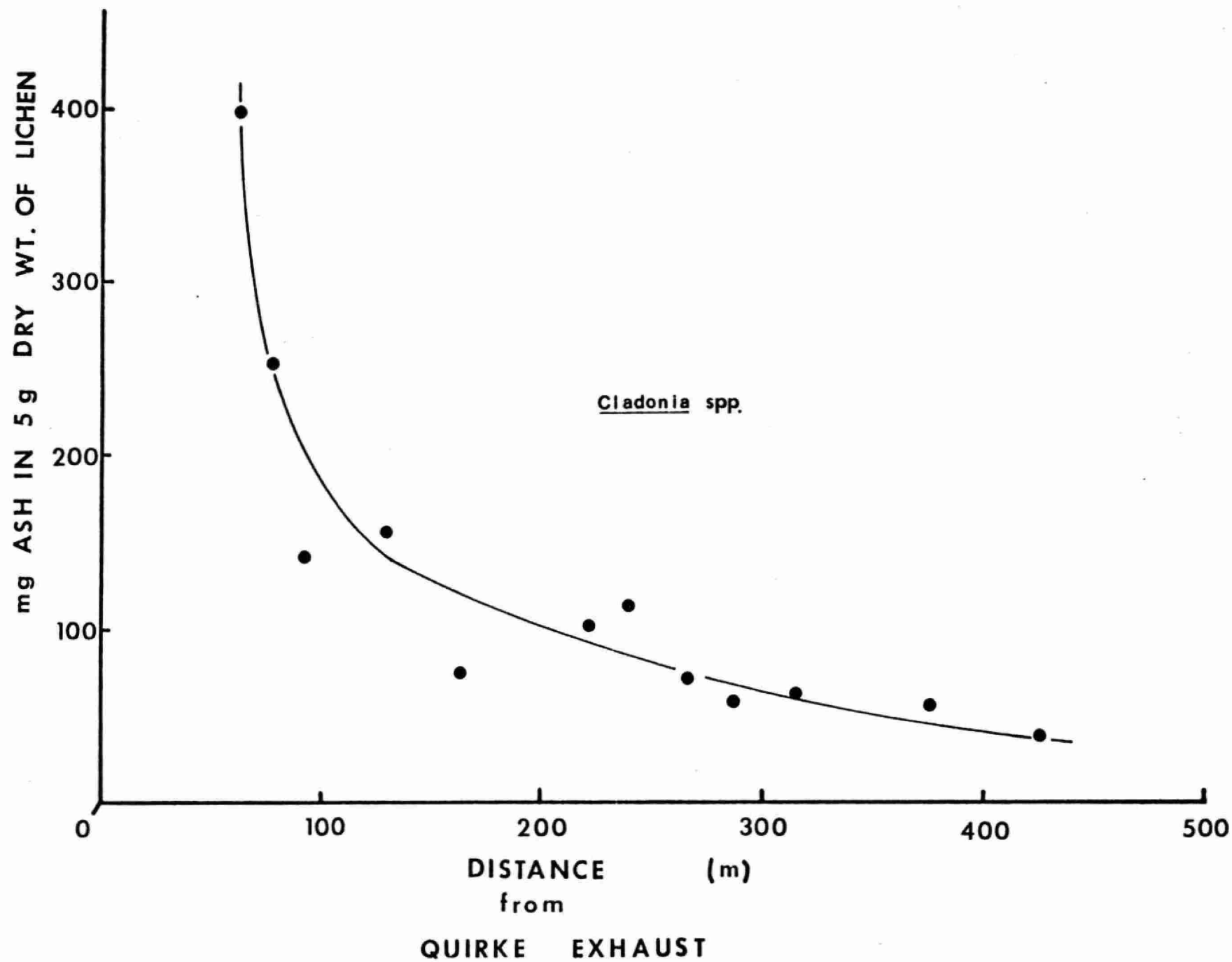


Fig. 18. Uranium content of some lichens and
mosses as a function of distance from
the vertical exhaust on Knowles Island
(site 1; see Appendix I).

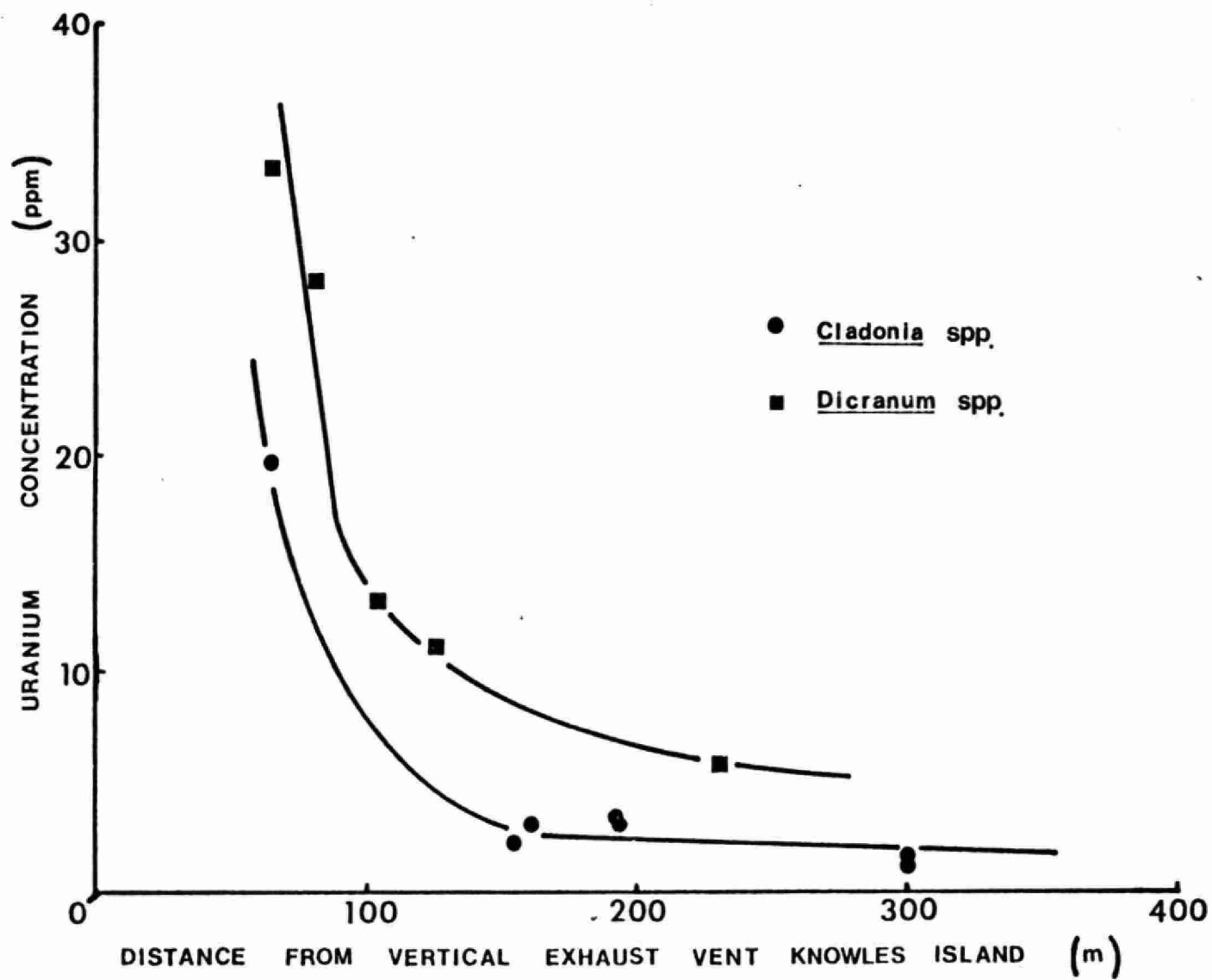
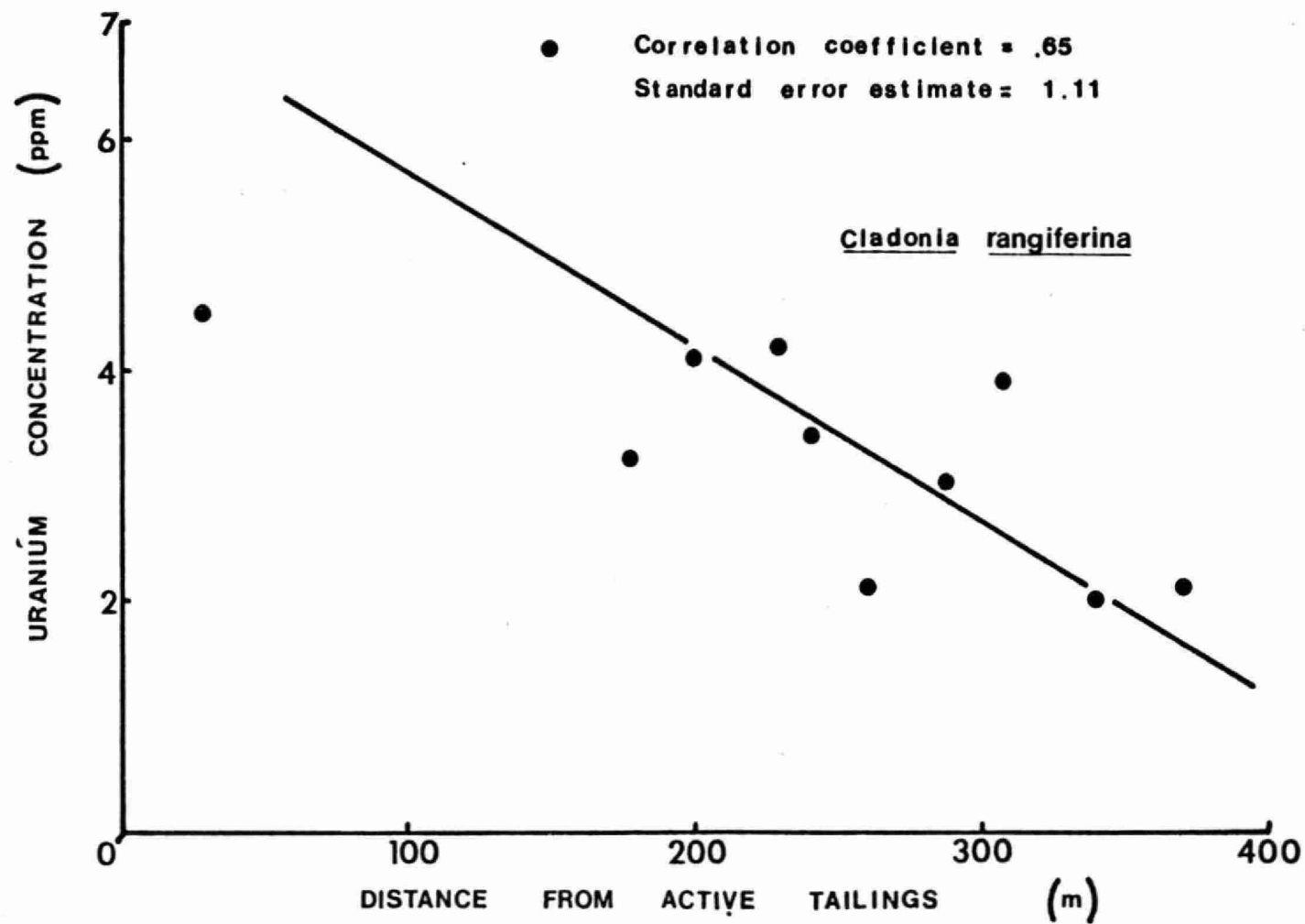


Fig. 19. Uranium content of Cladonia
rangiferina as a function of distance
from the margin of the Rio Algom Quirke
active tailings (site 10; see fig. 6).
The correlation coefficient and it's
standard error were calculated using
least squares fit of the data (Y-
residual minimization).



D. DISCUSSION

A large number of studies have employed lichens to monitor atmospheric deposition of metals around industrial or urban centres. A bibliography entitled "Recent Literature on Air Pollution and Lichens" provides access to these studies and is published regularly (e.g. Henderson and Hawksworth, 1979). Mosses have also been employed for the same purpose around similar emission sources and also used to assess fallout at a regional or countrywide level (Grodzinska, 1977; Rinne, 1977; and Steinnes, 1977). However, to date, neither lichens or mosses have been used to investigate contamination of the environment by uranium through industrial activity. The data provided in this report clearly indicate that these plants are useful monitors of uranium deposition around mills, exhausts and tailings. However, the one ppm detection limit of the X-ray fluorescence technique prevented the complete delineation of the zone of influence associated with emissions from the Elliot Lake operations. Presumably the levels of about 1 ppm uranium observed in lichens and mosses a few km from uranium mining activities should decrease gradually to ppb background levels. Demonstration of this requires a technique with a lower detection limit than the XRF procedure used routinely in this study. A promising new approach is electrothermal atomic absorption spectrophotometry (Tarui and Tokairin, 1979, Zatka, 1978). Since electrothermal AA capacity has recently been added to our research facilities, we propose to initiate development work to adapt electrothermal atomic absorption spectrophotometry for the analysis of ng quantities of uranium in plant samples. (Funds for this development work will be requested.)

In the present study, levels of about 100 ppm (dry wt) of uranium were observed in lichens and mosses close to mills and exhausts and up to 300 ppm of uranium were found in the aquatic moss Fontinalis from the Serpent River. To date, laboratory studies have not been done to determine the capacity for uranium uptake by various lichens and mosses. However Sakaguchi et al. (1978) report that fresh water algae incubated in a one ppm solution of uranium, accumulated from c. 1000 to c. 4000 ppm depending on the species of alga involved. In areas distant from uranium enrichment, very low levels of this element have been found in mosses (less than 0.2 ppm) (Steinnes, 1977). However near uranium rich rocks, Rhacomitrium contained 900 ppm in ash (c. 40 ppm dry wt.) and Hylocomium 100 ppm in ash (c. 1 ppm dry wt). Aquatic species of Sphagnum exhibited the highest uranium levels, i.e. 2,880 ppm in ash (c. 100 ppm dry wt.) (Yliruokanen, 1975). Rhacomitrium is an endohydric moss and thus uptake from the substrate might be expected to be considerable (see Richardson et al., 1980). The potential of lichens and mosses as uranium monitors will only be realized fully when laboratory studies have been completed. Information is required on uranium uptake capacity and kinetics as well as studies on uptake mechanisms. This sort of information is known for other elements for some lichens and mosses (e.g. Cladonia and Sphagnum) (see Nieboer et al., 1978; Richardson et al., 1980).

Around the uranium industry operations at both Elliot Lake and Agnew Lake, elevated levels of elements were found in the lichens and mosses close to emission sources. The levels decreased rapidly with distance. The dense tree cover probably enhances fallout by reducing wind speed and turbulence. We have previously shown that this sort of

fallout pattern would be expected if particles are being deposited under the influence of gravity (Nieboer and Richardson, 1980) and the plants are accumulating metals by both extracellular ion exchange and particulate trapping (Nieboer et al., 1978). The data displayed in this report clearly show that, of the elements analysed, Fe, Ti and U are emitted by uranium mining operations and accumulated by the lichens and mosses. Lichens and mosses close to the horizontal exhaust also showed enhanced Pb contents but specimens e.g. of Cladonia spp. collected at other sites around Elliot Lake and Agnew Lake showed levels of 26 ± 5 ppm and 26 ± 4 ppm respectively. These values would be expected for a semi-rural area of Northern Ontario (Tomassini, 1976). No doubt the Pb contribution from automobile exhausts masks Pb enrichment from vertical exhausts, mills and tailings. Distance related trends were also not seen for Ni. The fact that the average levels in lichens, e.g. Cladonia spp. (9 ± 1 ppm) around Agnew Lake were slightly higher than those around Elliot Lake (4 ± 1 ppm) suggests that there is a contribution from the Sudbury nickel smelters. Previous studies have shown that the zone of contamination from Sudbury extends up to about 150 km (Tomassini et al., 1976). This may well mask nickel enrichment from uranium mining sources but the data suggest that Ni is not an element emitted in significant amounts by the mining or milling processes.

As in previous studies, it was found that different genera absorbed different amounts of metals at a given site. However, trends through a transect were generally consistent. Steinnes (1977), in an extensive study on atmospheric deposition of trace elements in Norway using mosses and lichens, was able to calculate concentration factors relative to

Hylocomium for each species and for each element. There are not sufficient data for all the species in the present study to permit such a calculation. For subsequent investigations on uranium levels around Elliot Lake and Agnew Lake, it would be best to make extensive collections of a few species. The results to date suggest that Pleurozium and Dicranum would be suitable mosses and Cladonia or Stereocaulon suitable lichens. The first genus in each pair would be preferred because of ease of sample preparation. Fontinalis or aquatic Sphagnum species would be selected for studies on water quality in streams. The ease of sampling mosses and lichens and the results of this preliminary study, suggest that follow up investigations would be valuable for assessing the impact of the forthcoming expansions of the Uranium industry at Elliot Lake and Agnew Lake areas of Ontario. The evaluation of background levels for areas subject to new developments such as new mines or refineries prior to start up is especially recommended.

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APPENDIX I

Description of Micro-Transect Collection Sites.

(This material complements that given in section B.1.b., and site locations are shown in Figs. 2-4).

Site 1. Denison, Knowles Island Exhaust Transect (see Fig. 3).

Samples were collected at intervals from the large vertical exhaust vent going eastward across this island which was covered with mixed deciduous and coniferous trees.

Code: DBA1 - DBN2

Site 2. Denison, No. 1 Intake Shaft Transects (see Fig. 3).

Samples were collected in various directions from this intake shaft which will shortly be converted into an exhaust shaft. Construction to complete this conversion was underway.

Code: Northern transect, DCA1 - DCL3, DC01 - DCQ1

Southern collections, DCML and DCN1

Site 3. Denison, Barge Tie-up Point (see Fig. 3). A few samples were collected in a clearing behind the barge tie-up point.

Code: DAA1 - DAA3.

Site 4. Rio Algom, New Quirke No. 1 East Exhaust Transect (see Fig. 3). The transect direction was eastward in the same direction as the vent which exhausted horizontally. The transect was through a woodland area and was crossed at one point by a hydro line (Fig. 5).

Code: EEAL - EEJ3

21R1 - 32R1

Site 5. Denison Transect, Behind Mill (see Fig. 3). Samples were collected in a northerly direction behind the mill, down the slope towards Benner Lake and on the far side of Benner Lake. Most samples were collected beneath trees although a few, on the far side of the lake, were collected from open areas (south facing).

Code: DFA1 - DFA3, immediately behind mill.

DDA1 - DDC4, up-hill facing Benner Lake (facing away from mill)

DDD1 - DDE4, on far side of Benner Lake (facing mill).

Site 6. Denison Tailings Area South of Mill (see Fig. 3). Moss samples were collected adjacent to the tailings and dump areas.

Code: DEAL - DEC3.

Site 7. Rio Algom Quirke Mill (see Fig. 3). This sample was collected south of the mill about 90m from the storage tanks.

Code: ESID

Site 8. Serpent River, Upstream (South) of Quirke Mill (see Fig. 3). Samples were collected adjacent to the Serpent River on the flood plane.

Code: ESIA, ESIB, ESIC, ESIQ.

Site 9. Dunlop Lake Margin (see Fig. 3). Moss samples were collected along the lake margin and also in the lake.

Code: ESIE - ESIG

Site 10. Rio Algom, Quirke Active Tailings Transect (see Fig. 3). Quirke active tailings area was sampled by a transect running northeast from the margin of the tailings. The transect took into account the topography and wind direction (Fig. 6).

Code: 33R1 - 45V1

Site 11. Denison Active Tailings (see Fig. 3). Moss and lichen samples were collected on a small wooded knoll on the north side of the active tailings beyond the Denison gate.

Code: 01R1 - 02M1, Y, Z.

Site 12. Nordic Old Tailings East (see Fig. 4). Samples were collected up the slope (south facing) near the dam.

Code: 18C1, S, T.

Site 13. Nordic Old Tailings West (see Fig. 4). Lichens and mosses were collected in a wooded area at the west end of the old tailings.

Code: 15R1 - 17S1, N, O, P, R.

Site 14. Bog on Edge of Horn Lake (see Fig. 4). Moss was collected by the edge of a bog about 1 km from the road (main highway).

Code: ESIK

Site 15. Simpson Rd, Elliot Lake (see Fig. 4). Moss samples were collected on the slope, east of the highway near Simpson Road close to the hydro lines.

Code: C1 and C2

Site 16. Agnew Lake Operations area (see Fig. 2). Samples were collected near the precipitation pond, behind the leach pile, near the west exhaust and on the ridge above the hoist room.

Code: A0A1 - A0E2

APPENDIX II

List of Samples, Their Codes, and Collection Site
Details.

(Micro-transect sampling sites are described in
Appendix I and are shown in Figs. 2-4. Macro-
transect sites are depicted in Figs. 1 and 2.)

<u>Sample</u> <u>Code</u>	<u>Site</u> <u>Number</u> ^a	<u>Genus, species</u>	<u>Site Description</u> <u>Agnew Lake Macro Transect</u>
AMA1	MTA	Sphagnum rubellum	1.1 km - distance from mill
AMA2	MTA	Cladonia rangiferina	1.1 km
AMA3	MTA	Cladonia mitis	1.1 km
AMB1	MTA	Pleurozium schreberi	1.6 km
AMB2	MTA	Cladonia rangiferina	1.6 km
AMB3	MTA	Cladonia mitis	1.6 km
AMB4	MTA	Stereocaulon sp.	1.6 km
AMC1	MTA	Pleurozium schreberi	2.1 km
AMC2	MTA	Cladonia rangiferina	2.1 km
AMC3	MTA	Cladonia mitis	2.1 km
AMD1	MTA	Polytrichum sp.	3.1 km
AMD2	MTA	Fontinalis antipyretica	3.1 km (aquatic moss)
AMD3	MTA	Cladonia rangiferina	3.1 km
AMD4	MTA	Cladonia mitis	3.1 km
AME1	MTA	Polytrichum sp.	5.6 km
AME2	MTA	Cladonia rangiferina	5.6 km
AME3	MTA	Cladonia mitis	5.6 km
AME4	MTA	Stereocaulon sp.	5.6 km
AMF1	MTA	Cladonia rangiferina	8.0 km
AMF2	MTA	Cladonia mitis	8.0 km
AMF3	MTA	Pleurozium schreberi	8.0 km
AMG1	MTA	Cladonia rangiferina	9.6 km
AMG2	MTA	Cladonia mitis	9.6 km
AMG3	MTA	Pleurozium schreberi	9.6 km
AOA1	16	Cladonia mitis	collected at the west end of the precipitation pond
AOA2	16	Cladonia rangiferina	collected at the west end of the precipitation pond.
AOB1	16	Sphagnum sp.	collected by the creek below the west dam
AOC1	16	Dicranum sp.	collected near tailings road, 100 meters west of leach pile.
AOC2	16	Cladonia rangiferina	" " " " " " " " " "
AOC3	16	Pleurozium schreberi	" " " " " " " " " "
AOD1	16	Cladonia rangiferina	collected 50 ft from west exhaust fan.
AOD2	16	Cladonia rangiferina	collected 70 ft from west exhaust fan
AOD3	16	Cladonia rangiferina	collected on top of the ridge above w. exhaust fan-oppos. service area.
AOD2	16	Cladonia mitis	" " " " " " " " " " " " ramp
AOE1	16	Cladonia rangiferina	collected on the ridge behind the hoist room
AOE2	16	Cladonia mitis	" " " " " "

<u>Sample</u> <u>Code</u>	<u>Site</u> <u>Number</u> ^a	<u>Genus, species</u>	<u>Site Description</u> <u>Denison Mines Operations Area</u>
DAA1	3	Cladonia mitis	collected from clearing behind barge tie-up point.
DAA2	3	Cladonia rangiferina	" " " " " " "
DAA3	3	Pleurozium schreberi	" " " " " " "
DBA1	1	Polytrichum sp.	40 meters - distance east of vertical exhaust on Knowles Island.
DBB1	1	Polytrichum sp.	50 m
DBC1	1	Cladonia squamosa	65 m
DBC2	1	Dicranum sp.	65 m
DBD1	1	Dicranum sp.	80 m
DBE1	1	Dicranum sp.	103 m
DBF1	1	Dicranum sp.	125 m
DBG1	1	Cladonia mitis	154 m
DBH1	1	Cladonia rangiferina	160 m
DBH2	1	Umbilicaria muhlenbergii	160 m
DBI1	1	Pleurozium schreberi	162 m
DBI2	1	Dicranum sp.	162 m
DBJ1	1	Polytrichum sp.	170 m
DBK1	1	Cladonia mitis	192 m
DBL1	1	Cladonia rangiferina	193 m
DBM1	1	Dicranum sp.	230 m
DBN1	1	Cladonia rangiferina	330 m
DBN2	1	Cladonia mitis	330 m
DCA1	2	Dicranum sp.	7 meters - distance due north from intake shaft - to be converted to exhaust shaft.
DCA2	2	Pleurozium schreberi	7 m
DCB1	2	Polytrichum sp.	20 m
DCB2	2	Cladonia mitis	20 m
DCB3	2	Stereocaulon sp.	20 m
DCC1	2	Polytrichum sp.	24 m
DCD1	2	Cladonia rangiferina	29 m
DCD2	2	Stereocaulon sp.	29 m
DCE1	2	Cladonia rangiferina	44 m
DCE2	2	Cladonia mitis	44 m
DCF1	2	Polytrichum sp.	45 m
DCG1	2	Stereocaulon sp.	55 m (West end of ridge)
DCG2	2	Sphagnum actifolium	55 m (" " ")
DCG3	2	Cladonia mitis	55 m (" " ")
DCG4	2	Pleurozium schreberi	55 m (" " ")
DCH1	2	Pleurozium schreberi	55 m (east end of ridge)
DCH2	2	Sphagnum rubellum	55 m (" " ")
DCI1	2	Pleurozium schreberi	55 m (east end of ridge by rock)

Sample Code	Site Number ^a	Genus, Species	Site Description									
			Denison Mines Operations Area									
DCI2	2	Cladonia rangiferina	55 m	(east end of ridge by rock)								
DCJ1	2	Stereocaulon sp.	57 m									
DCJ2	2	Cladonia rangiferina	57 m									
DCJ3	2	Cladonia mitis	57 m									
DCK1	2	Sphagnum sp.	100 m	(in a hollow)								
DCL1	2	Cladonia mitis	150 m									
DCL2	2	Cladonia rangiferina	150 m									
DCL3	2	Pleurozium schreberi	150 m									
DCO1	2	Cladonia rangiferina	200 m									
DCO2	2	Polytrichum sp.	200 m	(due S.W. on ridge close to lake).								
DCP1	2	Cladonia rangiferina	250 m									
DCQ1	2	Cladonia rangiferina	no distance given	- due north of exhaust to be built.								
DCM1	2	Polytrichum sp.	20 m	due south of new exhaust shaft to be built.								
DCN1	2	Cladonia rangiferina	60 m	S.E. of new exhaust shaft to be built.								
DDA1	5	Sphagnum rubellum										
DDB1	5	Pleurozium schreberi	collected on	brow of hill overlooking Benner Lake	- facing away from mill.							
DDB2	5	Cladonia rangiferina	"	"	"	"	"	"	"	"	"	"
DDC1	5	Pleurozium schreberi	collected on	hill top overlooking Benner Lake	- facing away from mill							
DDC2	5	Cladonia rangiferina	"	"	"	"	"	"	"	"	"	"
DDC3	5	Cladonia mitis	"	"	"	"	"	"	"	"	"	"
DDC4	5	Polytrichum sp.	"	"	"	"	"	"	"	"	"	"
DDD1	5	Leucobryum glaucum	collected on	the opposite side of Benner Lake	- facing mill.							
DDD2	5	Polytrichum sp.	"	"	"	"	"	"	"	"	"	"
DDD3	5	Pleurozium schreberi	"	"	"	"	"	"	"	"	"	"
DDD4	5	Sphagnum subnitens	"	"	"	"	"	"	"	"	"	"
DDE1	5	Umbilicaria vellea	collected on	the opposite side of Benner Lake	facing mill on a 60' cliff.							
DDE2	5	Cladonia rangiferina	"	"	"	"	"	"	"	"	"	"
DDE3	5	Cladonia mitis	"	"	"	"	"	"	"	"	"	"
DDE4	5	Umbilicaria muhlenbergii	"	"	"	"	"	"	"	"	"	"
DEA1	6	Polytrichum sp.	collected by	tailings area S. of mill	- in hollow							
DEB2	6	Polytrichum sp.	"	"	"	"	- by dump area.					
DEC3	6	Polytrichum sp.	"	"	"	"	- adjacent tailings.					
DFA1	5	Polytrichum commune	collected on	hill behind mill	- bottom							
DFA2	5	Polytrichum commune	"	"	"	"	- middle					
DFA3	5	Polytrichum commune	"	"	"	"	- top					

Sample Code	Site Number ^a	GENUS, species	Site description	
			Rio Algom	
EEA1	4	Polytrichum commune	25 meters-distance from # 1 East exhaust shaft at Rio Algom.	
EEA2	4	Polytrichum commune	25 m	
EEB1	4	Polytrichum commune	50 m	
EEC1	4	Sphagnum acutifolium	75 m	
EEC2	4	Pleurozium schreberi	75 m	
EEC3	4	Polytrichum commune	75 m	
EED1	4	Polytrichum commune	125 m	
EED2	4	Sphagnum recurvum	125 m	
EEE1	4	Stereocaulon sp.	143 m (on rocks along side of road)	
EEF1	4	Sphagnum acutifolium	211 m (hydro clearing)	
EEF2	4	Polytrichum commune	211 m	
EEG1	4	Sphagnum acutifolium	425 m	
EEG2	4	Pleurozium schreberi	425 m	
EEH1	4	Sphagnum acutifolium	450 m	
EEI1	4	Pleurozium schreberi	470 m	
EEI2	4	Polytrichum commune	470 m	
EEJ1	4	Umbilicaria muhlenbergii	500 m (on rock in clearing near intake)	
EEJ2	4	Umbilicaria muhlenbergii	500 m " " " " " " "	
EEJ3	4	Umbilicaria deusta	500 m " " " " " " "	

			Moss Macro-Transect near Elliot Lake	
ESIA	8, MTE	Sphagnum recurvum	collected adjacent to the Serpent river on the flood plane. Upstream of Quirke Mill ca. 0.8 km.	
ESIB	8, MTE	Pleurozium schreberi	" " " "	
ESIC	8, MTE	Drepanocladus sp.	" " " "	
ESIQ	8, MTE	Pellia Neesiana	" " " "	
ESID	7, MTE	Pleurozium schreberi	collected adjacent to the Serpent R. ca. 90 metres from Quirke Mill Storage t.	
ESIE	9, MTE	Drepanocladus adunus	collected along the Dunlop Lk. margin ca. 3 km from Quirke Mill.	
ESIF	9, MTE	Sphagnum recurvum	" " " " " " "	
ESIG	9, MTE	Sphagnum rubellum	" " " " " " "	
ESIH	- MTE	Sphagnum recurvum	collected ca. 6.4 km from Quirke Mill.	
ESII	- MTE	Sphagnum subnitens	" " " " " "	
ESIJ	- MTE	Polytrichum commune	" " " " " " (upper stems)	
ESIP	- MTE	Polytrichum commune	" " " " " " (dead stems)	
ESIK	14, MTE	Sphagnum recurvum	collected on the NW edge of Horne Lake - 12.8 km from Quirke Mill.	
ESIL	- MTE	Sphagnum papillosum	" 25.6 km from Quirke Mill	
ESIM	- MTE	Sphagnum rubellum	" " " " " "	
ESIN	- MTE	Sphagnum magellanicum	collected on the Serpent R. Indian Reserve ca. 40 km from Quirke Mill.	
ESIO	- MTE	Fontinalis antipyretica	" " " " " " " " " "	

Sample Code	Site Number ^a	Genus, species	Site Description									
			Macro-Transect Along Hwy. 108									
Y	11, MTE	Pleurozium schreberi	(origin of transect-halfway between Rio Algom & Denison Mills). collected 1 km S. of origin on S. facing slope in front of Denison active trailings.									
Z	11, MTE	Pleurozium schreberi	"	"	"	"	"	"	"	"	"	"
01R1	11, MTE	Cladonia rangiferina	"	"	"	"	"	"	"	"	"	"
02M1	11, MTE	Cladonia mitis	"	"	"	"	"	"	"	"	"	"
03R1	MTE	Cladonia rangiferina	collected 3 km S. of origin - 25 m off hwy.									
04M1	MTE	Cladonia mitis	"	"	"	"	"	"	"	"	"	"
05R1	MTE	Cladonia rangiferina	collected 6 km S. of origin - 60 m off hwy.									
06S1	MTE	Stereocaulon sp.	"	"	"	"	"	"	"	"	"	"
07R1	MTE	Cladonia rangiferina	collected 10 km S. of origin - 30 m off hwy.									
09R1	MTE	Cladonia rangiferina	collected 23 km S. of origin - 23 m off hwy.									
10M1	MTE	Cladonia mitis	"	"	"	"	"	"	"	"	"	"
11R1	MTE	Cladonia rangiferina	collected 32 km S. of origin - 30 m off hwy.									
12M1	MTE	Cladonia mitis	"	"	"	"	"	"	"	"	"	"
13R1	MTE	Cladonia rangiferina	collected 54 km S. of origin - 100 m off hwy.									
14M1	MTE	Cladonia mitis	"	"	"	"	"	"	"	"	"	"

Nordic Old Tailings

15R1	13	Cladonia rangiferina	collected on the W. end of tailings area within 100 m (on E. facing rock).									
16S1	13	Stereocaulon sp.	"	"	"	"	"	"	"	"	"	"
17S1	13	Stereocaulon sp.	"	"	"	"	"	"	"	"	"	"
N	13	Brachythecium sp.	"	"	"	"	"	"	"	"	"	"
O	13	Moss	"	"	"	"	"	"	"	"	"	"
P	13	Pleurozium shreberi	"	"	"	"	"	"	"	"	"	"
R	13	Pohlia nutans	collected on 1972 revegetated area on tailings.									
18C1	12	Cladonia cristatella	collected on E. end of tailings within 100 m (south facing slope) near dam.									
S	12	Brachythecium sp.	"	"	"	"	"	"	"	"	"	"
T	12	Brachythecium sp.	"	"	"	"	"	"	"	"	"	"

Denison Old Tailings

19R1	Misc	Cladonia rangiferina	collected by the old Denison tailings - S.E. facing a slope.									
20M1	Misc	Cladonia mitis	"	"	"	"	"	"	"	"	"	"

Rio Algom

21R1	4	Cladonia rangiferina	63 meters - distance E of Quirke # 11 exhaust vent.									
22R1	4	Cladonia rangiferina	78 m									

<u>Sample</u> <u>Code</u>	<u>Site</u> <u>Number</u> ^a	<u>Genus, species.</u>	<u>Site Description</u>
			<u>Rio Algom</u>
23R1	4	Cladonia rangiferina	93 m - distance E of Quirke #21 exhaust vent.
24R1	4	Cladonia rangiferina	131 m
25R1	4	" "	165 m
26R1	4	" "	224 m
27R1	4	" "	242 m
28M1	4	Cladonia mitis	268 m
29R1	4	Cladonia rangiferina	288 m
30R1	4	" "	317 m
31R1	4	" "	378 m
31RD	4	" "	378 m
32R1	4	" "	427 m

Rio Algom Quirke Active Tailings Transect

33R1	10	Cladonia rangiferina	29 meters - distance NE from margin of Quirke active tailings
34S1	10	Stereocaulon sp.	151 m
35R1	10	Cladonia rangiferina	151 m
36R1	10	" "	177 m
37R1	10	" "	199 m
38R1	10	" "	231 m
39R1	10	" "	240 m
40R1	10	" "	259 m
41R1	10	" "	288 m
42R1	10	" "	307 m
43R1	10	" "	339 m
44R1	10	" "	369 m
45V1	10	Umbilicaria vellea	240 m

Moss Macro-Transect Along Hwy. 108

A	-	MTE	Pleurozium schreberi	collected 8 km N. of Elliot Lake town, at Quarter mile Road
B	-	MTE	" "	collected 4.8 km N. of Elliot Lake town.
C1	15,	MTE	" "	collected at Simpson Road in Elliot Lake town.
C2	15,	MTE	Brachythecium sp.	" " " " " "
D	-	MTE	Pleurozium schreberi	collected 12.8 km S. of Elliot Lake town (Terry's restaurant).
E	-	MTE	" "	collected 25.6 km S. of Elliot Lake town & 2.5 km N. of hwy 17E.
F	-	MTE	" "	collected 51.2 km S. of Elliot Lake town & 1.6 km W. of Massey on Hwy 17.

<u>Sample Code</u>	<u>Genus, Species</u>	<u>COMMENTS</u>
DBDD	Dicranum sp.	duplicate of DBD1
UN01	Cladonia rangiferina	unwashed duplicate of DC01
2EA1	Polytrichum commune	duplicate of EEA1
DBED	Dicranum sp.	duplicate of DBE1
DCJD	Cladonia mitis	duplicate of DCJ3
DCJZ	Cladonia mitis	duplicate of DCJ3
DDDD	Polytrichum sp.	duplicate of DDD2

- a. Sites numbered 1 to 16 are described in Appendix I and are shown in Figures 2 to 4. The designation MTE indicates the site is along the Elliot Lake Macro-transect (see section B.1.a. and Fig. 1). Similarly MTA refers to collection sites along the Agnew Lake Macro-transect (see section B.1.a. and Fig. 2). Misc refers to miscellaneous samples.



(9446)

MOE/ELL/LEV/ANWE

DATE DUE		

MOE/ELL/LEV/ANWE

Richardson, D H S

The levels of

uranium and other anwe

c.1 a aa